Urban Flourishing: Biosolar Effects on Urban Heat Island and Implications for Equity and Gentrification

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Building community-university partnerships for sustainability

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Humphrey School Capstone Report

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Executive Summary

In partnerships with the Humphrey School of Public Affairs, the University of Minnesota's Resilient Communities Project, and Macalester College, the Minnesota Metropolitan Council sought to support its Surface with Purpose tool, an application that projects the potential benefits of green roofs, solar photovoltaic panels and integrated BioSolar systems on public and commercial properties. The team from the Humphrey School of Public Affairs addressed two research questions that sought to further develop this tool:

1. To what extent do BioSolar systems impact the Urban Heat Island Effect?
2. What equity and gentrification considerations are important for policymakers to keep in mind when designing BioSolar System policies?
    a. Are BioSolar systems on commercial and public properties associated with an increased likelihood of surrounding neighborhoods to gentrify?

To answer these questions, the Humphrey School team conducted a literature review and key informant interviews on topics related to BioSolar elements (green roofs and solar photovoltaic panels), urban heat islands, and gentrification. To support this research in a Twin Cities context, the team also performed spatial analyses on urban heat islands and gentrification within the Metropolitan Council's jurisdiction. Lastly, the team conducted an exploratory econometric analysis of gentrification as it related to BioSolar elements within the Twin Cities area.

Findings

Urban Heat Islands (UHI)

Green roofs have the potential to reduce ambient air temperature by as much as 5.8° F, but may have little effect on thermal comfort at the pedestrian level. Green roofs are an important part of the solution to UHI and are most effective when combined with urban forestry initiatives. Several key informants stated that a city would need to reduce its proportion of impervious surfaces to below 50% in order to see substantial reductions in UHI. Solar panels have little direct impact on the UHI effect, but can help mitigate it by providing building shading and locally-produced energy. One study found that combining solar photovoltaic panels with green roofs (e.g. a BioSolar system) ultimately yields a net reduction in ambient temperature in urban areas when compared to a traditional rooftop. This study found that BioSolar systems are less effective at reducing ambient air temperatures than green roofs alone.

UHI poses the most immediate health risks to people ages 0-4 and 65+ and poses the greatest economic challenges and long-term health risks to low-income communities. Based on these criteria, the neighborhoods of Powderhorn Park, Lyndale, Phillips West, Ventura Village, Elliot Park, Cedar Riverside, Sumner-Glenwood, Near-North, Hawthrone, McKinley, and Folwell are most at risk in a Twin Cities metropolitan area.

BioSolar Developments and Gentrification

The literature reveals inequitable distribution of green developments, exacerbating already inequitable environmental risks to historically marginalized communities. Just as concerning, environmental justice literature often reveals a relationship between green developments and gentrification. There is evidence that the economic and existence value of green developments may raise property values in a given area and potentially displace economically disadvantaged residents. This is potentially an issue in the Twin Cities context, in which neighborhoods susceptible to gentrification experienced a much higher rate of green roof and solar panel installation between 2000 and 2010 than non-susceptible neighborhoods.

Surface with Purpose Recommendations

1. Add an Equity tab to the Surface with Purpose webpage to help reduce assumptions in climate resiliency planning. This section could focus on existing areas of environmental harm, income disparities, and gentrification at the scale used by the Metropolitan Council.
2. Within this tab, include tips for fostering collaboration with local communities on environmental justice. Tips could include ways of sharing information with local communities and ways to promote community education about BioSolar installation and maintenance.
3. Keep updated inventory of neighborhoods most at risk to public health and economic impacts from UHI, allowing policymakers to prioritize these areas.

Considerations for Collaboration with Community Members

Interviews with key informants revealed major areas of consideration for BioSolar developments. These areas affect either the location or the design of the BioSolar system and are meant to be used on individual projects, rather than on the Surface with Purpose initiative as a whole.

1. Geographic Considerations
    a. Public Benefits
    b. Property Values
2. Functional Considerations
    a. Private Benefits
    b. Access
    c. Maintenance, Sustainability, and Longevity

Chapter One: Introduction

1.1 Background

The Metropolitan Council approved the Thrive MSP 2040 plan in 2014. The plan acknowledges that the region faces emerging environmental challenges from global climate change, including severe weather patterns and extreme heat (Metropolitan Council, 2014). In counties under the Metropolitan Council's jurisdiction, climate change could decrease agricultural productivity by roughly 10%, increase energy expenditures by 5-10%, and increase the cost of direct damages to society by roughly 5% by the year 2100 (Hsiang et al, 2017). Three of the plan's seven guidelines concerning land use and development focus on environmental goals: water sustainability, natural resources protection, and building in resilience. This last goal cites the need to reduce energy consumption and greenhouse gas emissions, and increase urban forestry.

Surface with Purpose is a tool for facilitating urban resilience. Launched in August 2020, the "Surface with Purpose Tool quantifies potential climate-change mitigation effects from green roof and BioSolar development on large rooftops and surface parking lots across the Twin Cities region" (Metropolitan Council, 2020) and outlines land-use and property-level information.

These elements inform policymakers in governments under the Metropolitan Council's jurisdiction about the opportunities for climate change mitigation within their spheres of influence. With the qualitative and quantitative information provided by the Surface with Purpose tool, the Metropolitan Council can better facilitate urban resilience strategies within the metropolitan region.

1.2 Purpose of Study

The Metropolitan Council is interested in the impacts of BioSolar systems, consisting of solar energy systems and green roof technologies, and is developing the Surface with Purpose tool to facilitate the installation of BioSolar systems on public and commercial buildings.

The Surface with Purpose tool is designed to:

1. Demonstrate the potential value of BioSolar systems
2. Help communities and practitioners make more informed climate resilience investments
3. Inform regional policy, planning, and development of these technologies to promote greater climate resilience across the region

This study was requested by the Metropolitan Council and was prepared by a research team from the Humphrey School of Public Affairs. The study's objectives were to address gaps in the Surface with Purpose tool regarding how the UHI Effect would be affected by BioSolar systems and how climate change strategies interlink with gentrification. This study provides data on the impact of BioSolar systems on UHI effects, policy recommendations for addressing the relationship of climate change strategies on gentrification, and policy considerations specific to equity in BioSolar system design and installation. Two research questions were developed to address these goals:

1. To what extent do BioSolar systems impact the Urban Heat Island Effect?
2. What equity and gentrification considerations are important for policymakers to keep in mind when designing BioSolar System policies?
    a. Are BioSolar systems on commercial and public properties associated with an increased likelihood of surrounding neighborhoods to gentrify?

One of the Thrive MSP 2040 plan's major outcomes is equity, defined as "recognizing institutional and systemic barriers and creating access and opportunities that benefit all"[1]. With outcome in mind, this study looks at both generalizable policy recommendations for the Surface with Purpose initiative and at policy considerations at the ground level for individual BioSolar installations.

1.3 Research Methods

This report draws upon four main elements of research:

- Literature review of academic articles, policy papers, technical papers, governmental guides, green roof and solar PV-related reports, and organizational technical guides
- Eight key informant interviews of environmental justice activists, small business owners, policy practitioners in and out of government, and academic researchers
- Spatial analysis of UHI and gentrification within the Metropolitan Council's jurisdiction
- Econometric analysis of green roofs, solar PVs, and BioSolar Systems' relationship with gentrification

The following paragraphs explicate our literature review process, we describe our spatial and econometric analysis methods more in their respective chapters.

We first reviewed articles, papers, and reports provided by the Metropolitan Council. These publications described how climate change mitigation measures could reduce UHI and improve urban environments. From there, our review split into two sections: 1) Urban Heat Island effects, with a special emphasis on how measurements were made to confirm environmental improvement, and 2) experiences of gentrification and its relation to the introduction of green infrastructure. Key search terms included 'Urban Heat Island', 'Green Roofs', 'Solar Energy', etc. We limited our academic literature to peer-reviewed publications.

We also explored databases and literature promoted by organizations and groups related to our topics of interest for working or white papers that provide context specific information about

[1] Equity - Metropolitan Council (metrocouncil.org)

BioSolar systems, green roofs, and solar PVs. These sources contributed to our understanding of BioSolar system interactions with Urban Heat Island, gentrification, and equity. Various governmental agencies, such as the Environmental Protection Agency, were also used to ground our research in commonly accepted vocabulary.

Anecdotal evidence was gathered through key informant interviews on the topics of green roofs, solar PV panels, BioSolar systems, and gentrification. We used a snowball sampling method and worked to ensure a diverse collection of key informants both in terms of expertise and demographically. Terminology used to describe technical and/or anecdotal information in our Annotated Bibliography can be found in Appendix A.

1.4 Report Organization

This report is organized into four chapters:

1. Introduction
2. BioSolar Systems' Impact on Urban Heat Islands
3. Equity and Gentrification in Context with BioSolar System Policies
4. Surface with Purpose Recommendations and Collaboration Considerations

Appendices contain further detail on key terminology for the study and analytical results from chapter 3.

Chapter Two: BioSolar Systems' Impact on Urban Heat Island

2.1 Urban Heat Island Literature Review

The urban heat island (UHI) is the phenomenon of urban areas experiencing higher temperatures than surrounding suburban and rural areas. It is defined as the difference between urban temperature and rural core temperature (Oke, 1987). Higher urban temperatures exist for several reasons: excess storage of solar radiation by surfaces with low albedo, tall buildings absorbing and re-emitting solar radiation, high proportions of impervious surfaces resulting in a low level of evapotranspiration, non-circulation of urban air due to wind-blocking buildings and other structures, and the release of anthropogenic heat (Oke et al., 1991).

Heat islands are the most documented phenomenon of climate change (Santamouris, 2012). UHIs contribute to several public health and economic issues. Higher temperatures result in higher demand for air conditioning, thereby raising energy bills and increasing the amount of energy emissions. These emissions contain pollutants that are harmful to human health and contribute to the formation of smog, acid rain, and fine particulate matter (EPA, 2020). Higher urban temperatures contribute to higher rates of heat-related illness and death in large cities, with people aged 0-4 and 65+ being most at risk (Clarke, 1972; CDC, 2020).

The UHI effect varies throughout urban landscapes and disproportionately impacts low-income communities and communities of color (Hsu et al., 2020). Across the United States' largest cities, neighborhoods that are predominantly occupied by Black and Hispanic residents are, on average, 1.2-1.7° C (2.1-3.1° F) warmer than neighborhoods occupied by predominantly white residents (Hsu et al., 2020). Similar trends exist when examining impoverished census tracts' relationship to heat (Hsu et al., 2020).

As climate change continues to progress, the average temperature of the Twin Cities Metropolitan Area (TCMA) will rise, with the number of days above 95° F increasing by up to 31 days per year compared to 1990 by 2090 (Noe et al., 2019). This means that the residents of the TCMA will be at increased risk of heat-related illness and death, higher energy bills, and worsened air quality. For example, Minneapolis's historically racist housing policies such as redlining have segregated communities of color into neighborhoods that are up to 10° F hotter than other parts of the city (Borunda, 2020). If current trends continue, TCMA's low-income residents and residents of color will face the worst impacts of increasing urban temperatures.

2.1.1 Green Roofs

Green roof systems have the potential to mitigate the UHI. For the average American city, roofs account for 20-25% of urban surface area and 30-40% of impervious surface area (Akbari and

Rose, 2008; Hutchinson et al., 2003; Oberndorfer et al., 2007). Since UHIs are partly caused by low-albedo surfaces absorbing and re-emitting large amounts of heat from the sun, and green roofs are typically made of high-albedo materials, installing vegetation on top of roofs will help increase the heat-reflecting capacity of a large portion of the urban landscape, thereby reducing the UHI effect. Green roofs also contribute to UHI mitigation by increasing the vegetation density of urban environments (EPA, 2020). The potential cooling effect of green roofs in the TCMA is further discussed later in this report.

Green roofs can cool roof surface temperatures by 60-80° F (EPA, 2020; MN Green Roofs Council, 2020). For example, here in the TCMA, a green roof installed on the Target Center reduced the surface temperature by as much as 80° F, depending on the temperature of the day (MN Green Roofs Council, 2012). Reductions in surface temperature of roofs translates into cooler temperatures in the surrounding area, typically about 1-2° C (1.8-3.6° F). The reduction can be greater, however. For instance, a model developed for New York City shows that installing green roofs around the entire city would decrease the average air temperature of the city by as much as 3.2° C (5.8° F), assuming that 100% of suitable surfaces had green roofs installed (The Effects of GRs on Ambient Temperatures, Helow, 2018).

Numerous studies have been conducted on estimating the cooling potential of green roofs in various cities around the world. One literature review shows that green roofs have the potential to reduce ambient temperature 0.3°C and 3.2°C. Models show that the maximum temperature reduction will occur at the roof level, but cooling effects will extend into ambient temperatures at street level as well. The results of several studies are summarized in Table 2.1.

Table 2.1 Studies on the Mitigation Potential of Green Roofs on Ambient Temperature

Reference Work	Study/Location	Type of Study	Mitigation Potential
Bass et al, (2002)	Toronto, Canada	Simulation	Temperature reduction between 1-2°C
Liu & Bass, (2005)	Toronto, Canada	Simulation	Temperature reduction of 2°C
Rosenzweig et al, (2006)	New York City, US	Simulation	Average temperature reduction of 1.4°C
Orberndorfer et al, (2007)	Toronto, Canada	Simulation	Temperature reduction of 2°C
Peng & Jim, (2013)	Hong Kong, China	Simulation	EGR temperature reduction of 0.7°C IGR temperature reduction of 1.7°C
Santamouris, (2014)	Various	Simulation & Experimental	Temperature reduction be 0.3 - 3°C
D. Li et al, (2014)	Washington, US	Simulation	Temperature reduction of 0.5°C
MacIvor et al (2016)	Toronto, Canada	Experimental	Average temperature reduction of 2°C at 6 feet above green roof surface

*Table is adapted from Helow (2018)

The UHI mitigation potential of a green roof is dependent on several factors. One of the primary ways that green roofs mitigate the UHI is through evapotranspiration, and a green roof that is regularly irrigated will have greater evapotranspiration potential and therefore more cooling potential (Helow, 2018; Li et al., 2014). The density of vegetation on a green roof, as well as the material that pathways are made out of, can have an impact on the albedo of the surface area of a green roof surface area and therefore the cooling potential (EPA, 2020). UHI mitigation potential is also dependent on the climate of the green roof's locality and proximity of the roof to pedestrian level (Kolokotsa et al., 2013).

Green roofs can either be extensive or intensive. Intensive green roofs have deeper growing mediums and typically have more diverse vegetative covering. Extensive green roofs have shallower growing mediums and typically consist primarily of low-growing grasses. Some studies have shown that, despite their vegetative differences, they perform comparably to each other when it comes to reductions in UHI (Kats and Glassbrook, 2018). This is likely because albedo levels are not significantly different between extensive and intensive green roofs (EPA, 2008). However, other studies have indicated that vegetative and soil differences do make a difference, and that the presence of sedum plants and compost in a green roof's growing medium significantly increases its cooling effect (MacIvor et al., 2016).

Green roofs may have further indirect impacts on UHIs, such as through energy use reductions within the building on which a green roof is built and associated reductions in heat emissions from the building; however, these impacts on UHI are difficult to quantify.

Some studies indicate that installing green roofs on their own will have little-to-no effect on thermal comfort at the pedestrian level, particularly in areas with tall buildings. As noted above, reductions in ambient temperature range from 0.3-3.2° C (0.5-5.8° F). When working within neighborhoods that reach temperatures of over 100° F, such a small difference may not have a significant impact on quality of life or health outcomes. UHI mitigation is significantly higher when green roofs are combined with trees and green walls (Herath et al., 2018). When planning for UHI mitigation, it is important to consider other strategies in addition to green roofs and BioSolar systems.

2.1.2 Solar Panels

Our research revealed relatively little on the relationship between solar panel installations and the UHI effect. The studies we reviewed indicate that solar panels have little effect on decreasing the amount of solar radiation that is absorbed and then re-emitted. However, the shading of buildings and locally-produced energy they provide can help decrease the impacts of the UHI effect by reducing the heat given off when cooling buildings during hot summer days.

One study found that a large deployment of rooftop solar panels in the city of Paris, France would result in insignificant changes in ambient temperature, but would reduce the energy needed for air conditioning in the city by 12% (Masson et al., 2014). Another study indicates that in Sydney, Australia, the installation of solar panels around the city could reduce the maximum temperature of the city by up to 1°C (1.8°F) (Ma et al., 2017). In this case, the reductions in ambient air temperature were primarily due to the decreased need to import energy, as the solar panels provided locally-produced electricity (Ma et al., 2017).

2.1.3 BioSolar Systems

Although we found a significant amount of research about green roofs' ability to mitigate the UHI, our literature review revealed relatively little research on the UHI mitigation potential of green roofs integrated with photovoltaic systems. As discussed above, green roofs can contribute to reductions in the UHI, while solar panels can have little-to-no impact. One study revealed that when the two are combined into BioSolar systems, they contribute to a net reduction in ambient temperature in urban areas compared to traditional rooftops (Scherba, 2011). Green roofs on their own result in an approximate 75% reduction in rooftop temperatures in Minneapolis, while solar panels integrated with green roofs result in an approximate 50% reduction (Scherba, 2011).

2.2 Key Informant Interviews

Key informant interviews on green roofs, solar panels, and BioSolar systems' ability to mitigate the UHI were consistent with what we found in the scientific literature. Several key informants stated that a city would need to reduce its proportion of impervious surfaces to below 50% in order to see the magnitude of UHI reductions predicted in these studies, regardless of whether impervious surfaces were replaced with green roofs or other permeable surfaces. Several of our key informants suggested that the most dramatic reductions in UHI would be experienced in the areas with the highest density of impervious surfaces, such as downtown areas. The expected reductions in UHI would be less further out from city centers, as urban areas grew more suburban and the coverage of impervious surfaces became less dense.

2.3 Planning for BioSolar Implementation for Urban Heat Island Mitigation using Surface With Purpose

Our literature review and key informant interviews did not reveal a functional relationship between additional units of BioSolar and decreased urban temperatures that could be easily incorporated into the Surface With Purpose tool. This is likely due to the extremely contextual nature of green roofs' impact on the UHI: climate characteristics, maintenance practices, building height, and several other highly variable factors all impact how effective a green roof system will be at mitigating heat islands.

In order to make our research as useful to planners as possible, we instead developed a set of criteria that indicate a census tract's vulnerability to the health and economic harms caused by higher temperatures resulting from the UHI effect. When planning for BioSolar implementation, these tracts could be prioritized in order to help maximize the net benefit of BioSolar system installation. We display the information spatially at the end of this section so that it can be easily incorporated into the Surface With Purpose tool.

Our literature review revealed that air conditioning becomes significantly more important for heat-illness prevention at temperatures above 95° F. Additionally, we found that green roofs have the highest potential for UHI mitigation in neighborhoods that are more than 50% covered by impervious surfaces. We also found that people ages 0-4 and 65+ are most at risk for heat related illness, and that low-income communities are most at risk for health and economic challenges posed by UHIs. Prioritizing census tracts that meet these characteristics for BioSolar implementation will help ensure that the net social benefit of installing the systems is maximized by reducing the health and economic risks that are borne by these communities.

Accordingly, it is important to prioritize BioSolar installation in census tracts that meet the following criteria:

1. Experience temperatures of more than 95° F on hot summer days and have surface areas that are greater than 50% impervious surfaces.
2. Are areas of concentrated poverty
3. Have a significant proportion of residents aged 0-4 (10% or greater) and/or 65+ (10% or greater)

An area of concentrated poverty (ACP) is a census tract where 40% or more of residents are living with incomes below 185% of the federal poverty threshold (Metropolitan Council, 2018). We used tracts' status as ACPs as an indicator that it is low-income and at risk of the economic challenges posed by high urban temperatures.

Data on surface temperature, people aged 65+, ACPs, and environmental justice areas of concern are available in the Metropolitan Council's "Equity Considerations for Place-Based Advocacy in the Twin Cities Region" dataset. Data on people aged 0-4 was collected from the American Community Survey's 2015-2019 estimates, and data on impervious surface coverage was collected from the "Minnesota Land Cover Classification System" dataset provided by the Minnesota Department of Natural Resources.

Maps of census tracts experiencing UHI, as well as tracts meeting criteria 1, 1 and 2, 1 and 3, and all three were created using ArcGIS Pro and are displayed below in Figures 2.1-5.

Figure 2.1. Census tracts that experience an average temperature of at least 95°F on a hot summer day

High temperatures primarily impact Minneapolis, Saint Paul, nearby suburbs, and the area around the Minneapolis-St. Paul International Airport. The highest temperatures are clustered around downtown Minneapolis, downtown St. Paul, and along the Interstate 94 corridor.

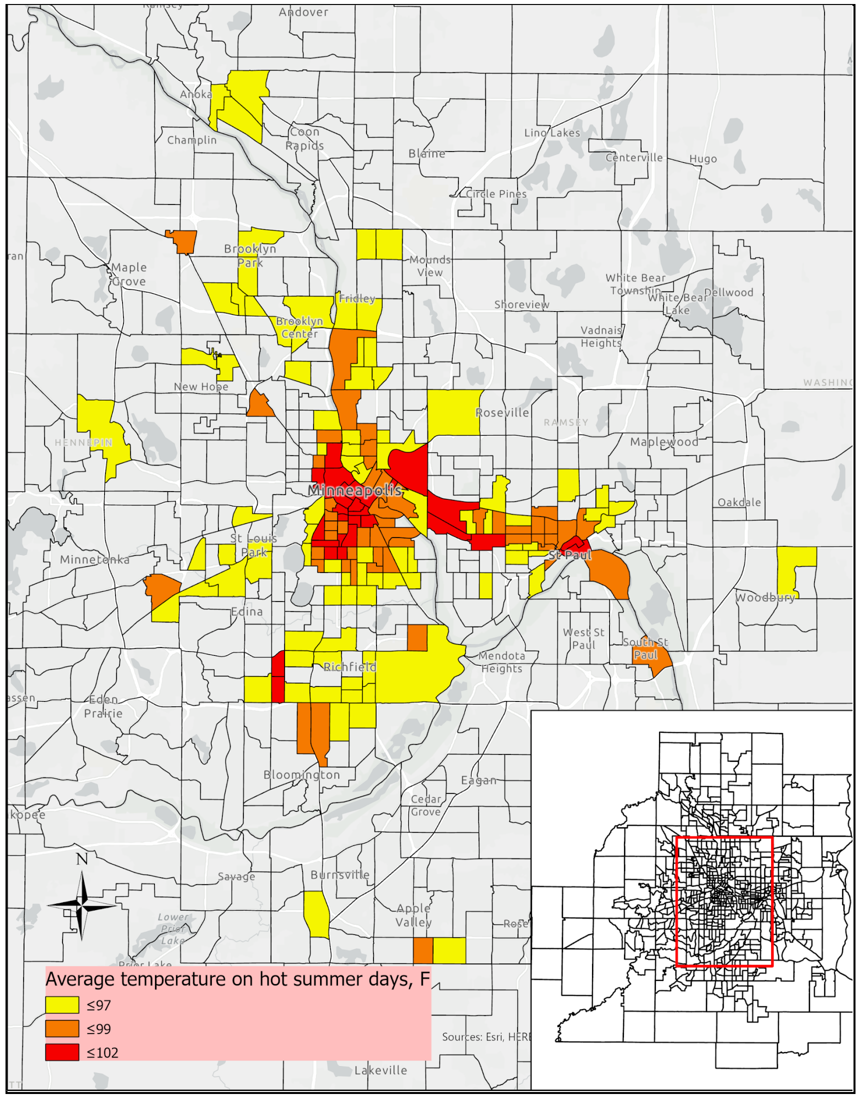


Table 2.2 Summary of TCMA census tracts experiencing the UHI effect

Average temperature on hot summer day (°F)	Number of census tracts	% of TCMA census tracts	% of TCMA population	Total surface area (miles^2)	% of TCMA surface area
95-97	96	13.6%	11.3%	76.6	2.6%
97-99	45	6.4%	4.8%	22.8	0.8%
99-102	24	3.4%	3.4%	11.9	0.4%
Total	*165*	*23.4%*	*19.5%*	*111.3*	*3.8%*

Figure 2.2. Census tracts that are 95°F+ on hot summer days and that are >50% covered by impervious surfaces

The census tracts with the highest proportions of impervious surfaces are located in Central and South Minneapolis. Note: The land use dataset used in this study did not include data on much of St. Paul, primarily around the Rondo neighborhood. Accordingly, this map may not show all areas of concern.

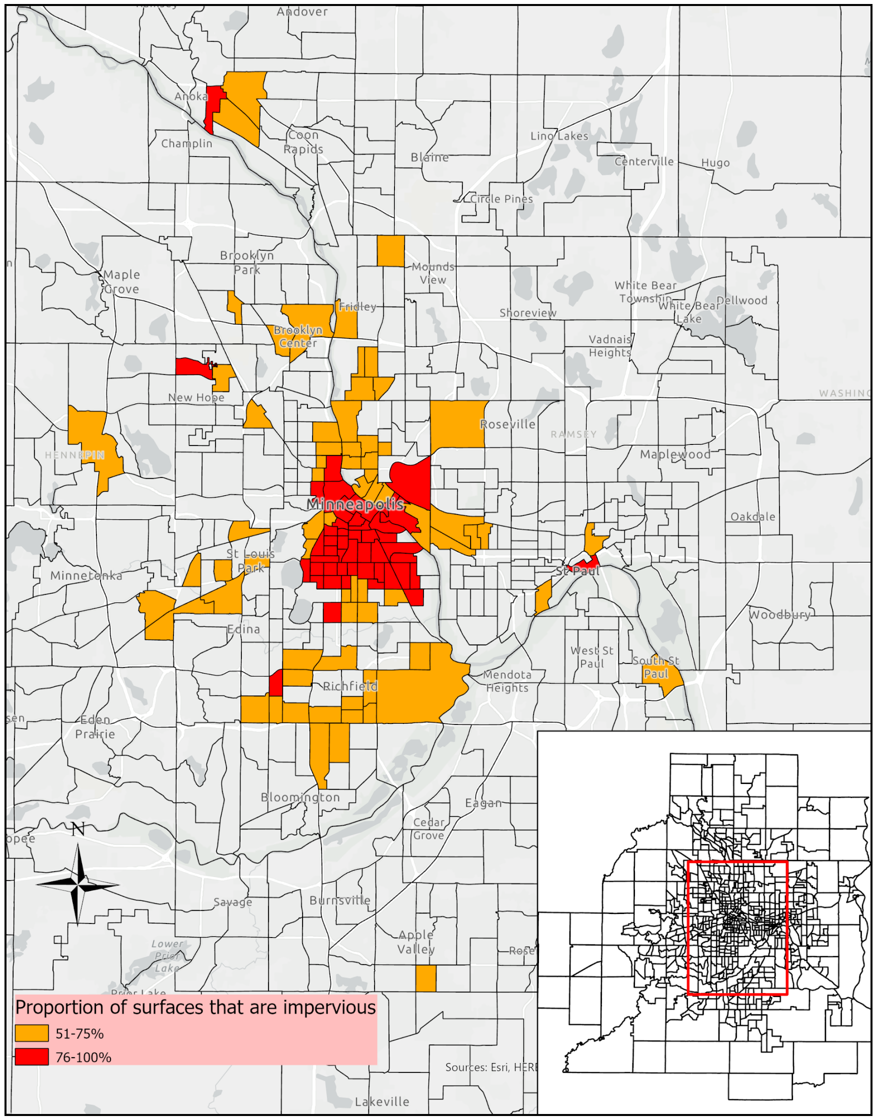


Table 2.3 Summary of TCMA census tracts that experience the UHI effect and have >50% impervious surface coverage

Proportion of surfaces that are impervious	Number of census tracts	% of TCMA census tracts	% of TCMA population	Total surface area (miles^2)	% of TCMA surface area
51-75%	70	9.9%	8.1%	60.5	2.0%
76-100%	48	6.9%	6.4%	18.8	0.6%
Total	*118*	*16.8%*	*14.5%*	*79.3*	*2.6%*

Figure 2.3. Census tracts that are 95°F+ on hot summer says, are >50% covered by impervious surfaces, and are areas of concentrated poverty

Areas of concentrated poverty that experience high temperatures are abundant in Minneapolis and St. Paul, as well as around the airport and in northern suburbs. By definition, these census tracts are also areas of environmental justice concern.

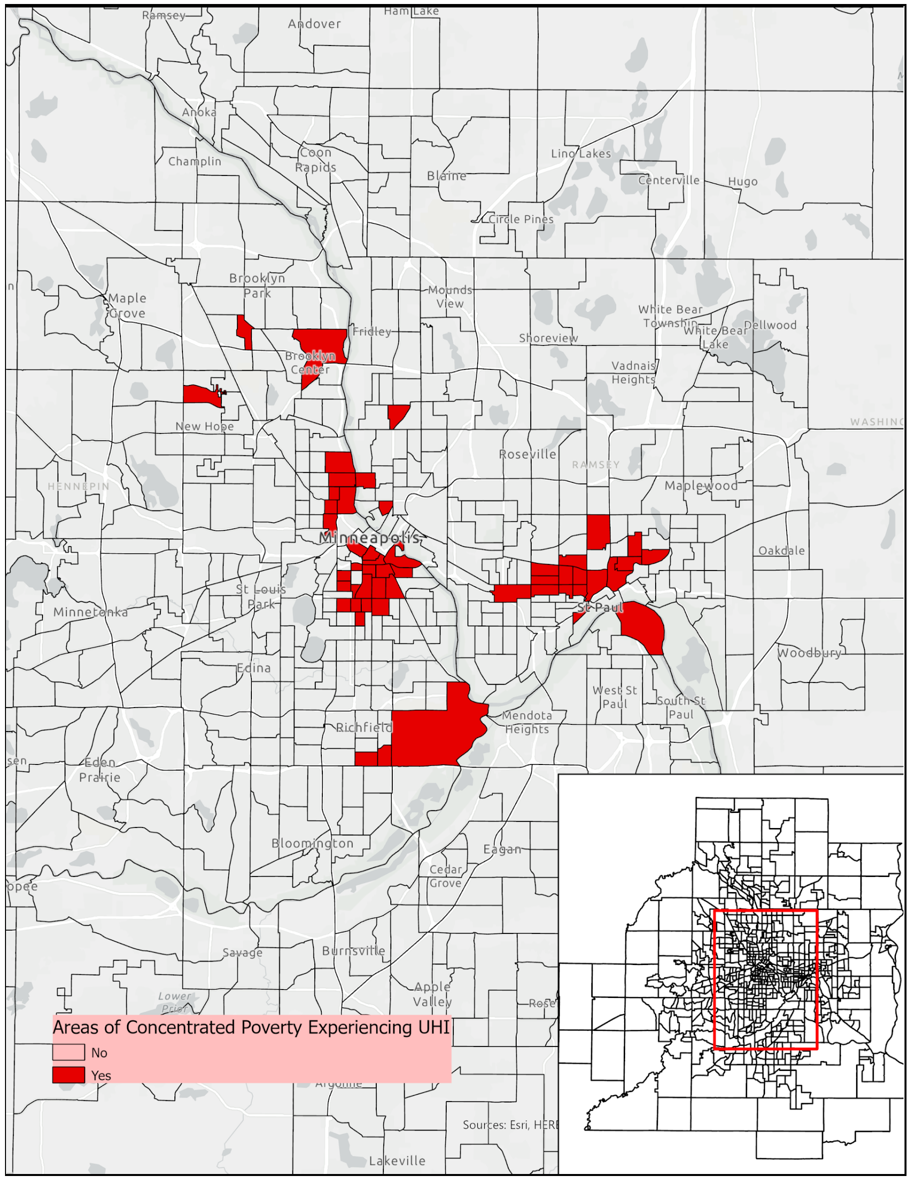


Table 2.4 Summary of TCMA census tracts that experience the UHI effect and are ACPs

Number of ACP census tracts experiencing UHI	% of TCMA census tracts	% of TCMA population	Total surface area (miles^2)	% of TCMA surface area
51	7.2%	5.6%	28.8	1.0%

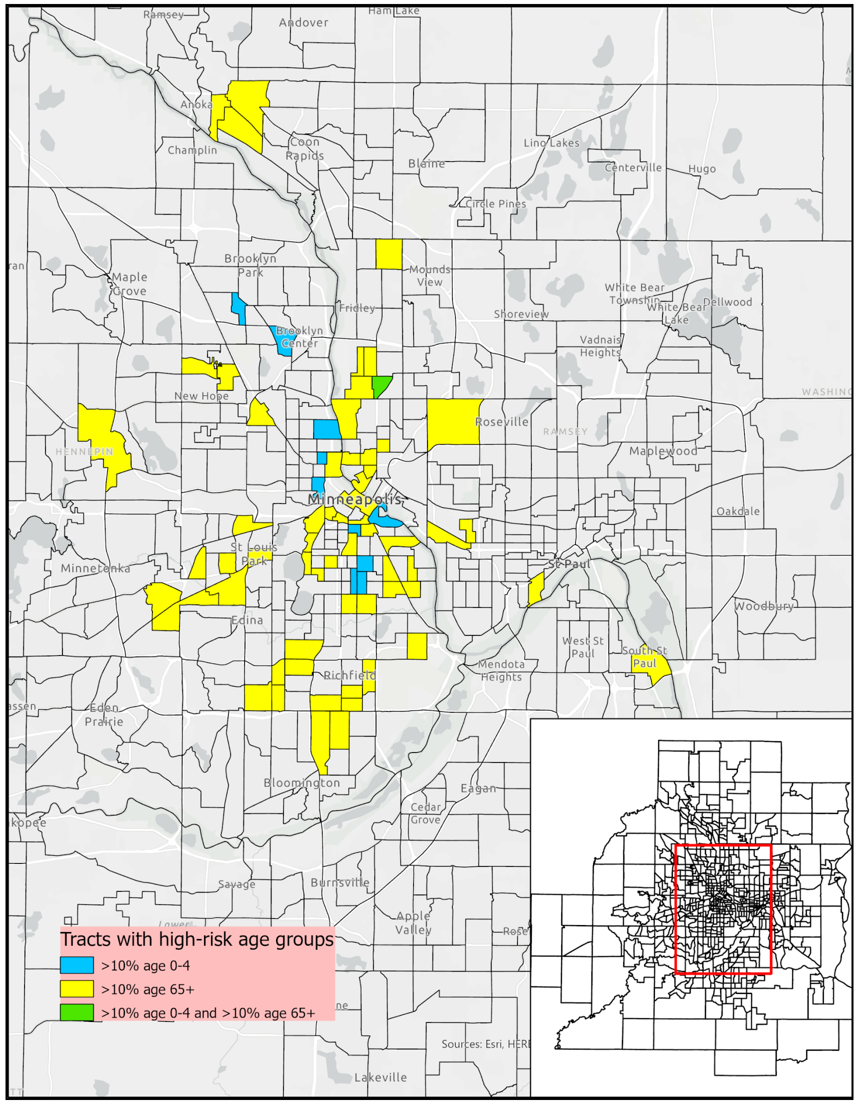


Figure 2.4. Census tracts that are 95°F+ on hot summer says, are >50% covered by impervious surfaces, and have a significant proportion of residents in high-risk age groups

Census tracts with large proportions of high-risk age groups are scattered throughout the Twin Cities Metropolitan Area with no clear geographic trend. There are significantly more tracts with high proportions of residents aged 65+ than aged 0-4.

Table 2.5 Summary of TCMA census tracts that experience the UHI effect and have high proportions of high-risk age groups

Proportion of high-risk age group	Number of census tracts	% of TCMA census tracts	Total surface area (miles^2)	% of TCMA surface area
>10% age 0-4	9	1.3%	4.2	0.1%
>10% age 65+	62	8.8%	45.2	1.5%
Both	1	0.1%	0.5	<0.1%
Total	*72*	*10.2%*	*49.9*	*1.7%*

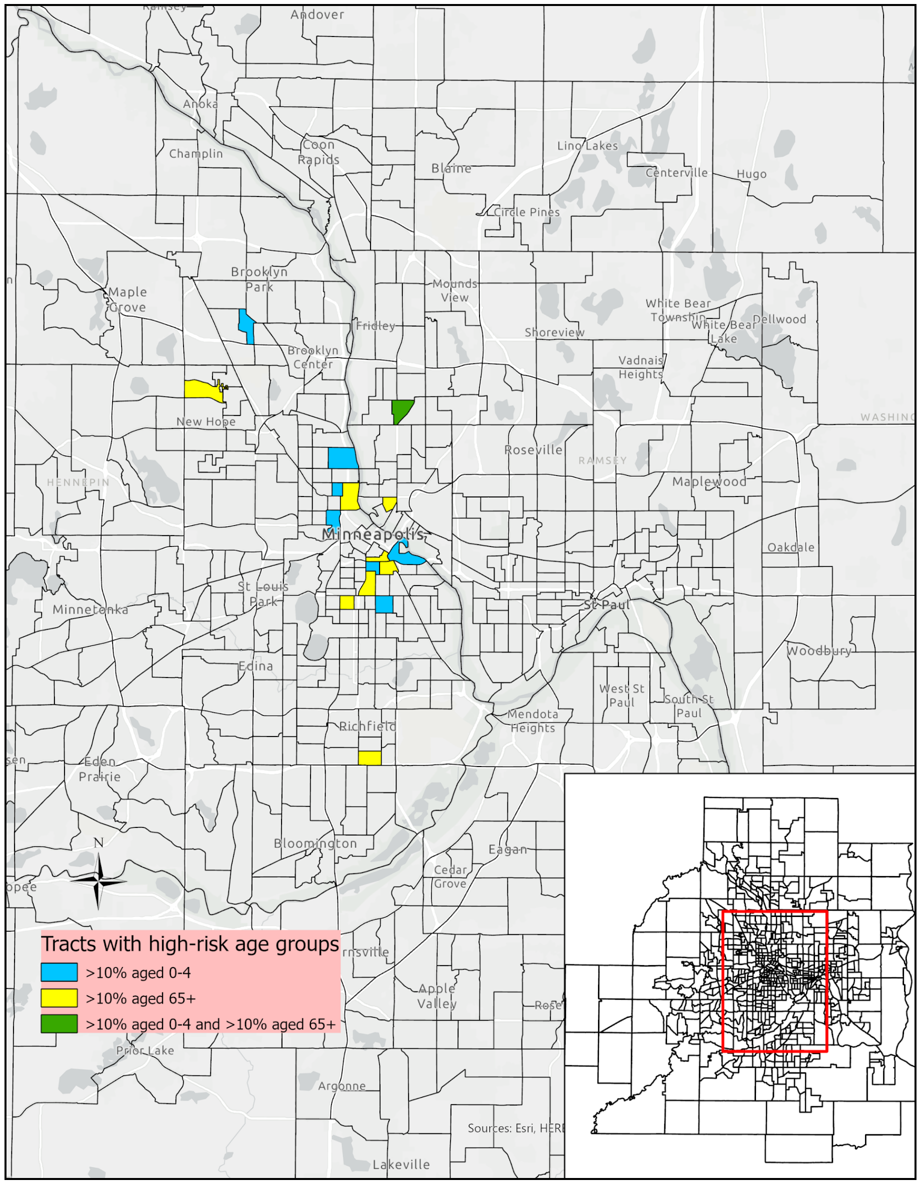


Figure 2.5. Census tracts that are 95°F+ on hot summer says, are >50% covered by impervious surfaces, are areas of concentrated poverty, and have a significant proportion of residents in high-risk age groups

Census tracts that meet all criteria we identified as risk factors for UHI include neighborhoods in Columbia Heights, New Hope, Brooklyn Center, and Richfield; as well as the following neighborhoods of Minneapolis: Powderhorn Park, Lyndale, Phillips West, Ventura Village, Elliot Park, Cedar Riverside, Sumner-Glenwood, Near-North, Hawthrone, McKinley, and Folwell. The land use dataset used in this study did not include data on much of St. Paul, primarily around the Rondo neighborhood. Accordingly, this map may not show all areas of concern.

Our spatial analysis reveals that the greatest risk for the negative consequences of the UHI effect falls in North and Central Minneapolis. The neighborhoods of Powderhorn Park, Lyndale, Phillips West, Ventura Village, Elliot Park, Cedar Riverside, Sumner-Glenwood, Near-North, Hawthrone, McKinley, and Folwell all meet all of the risk criteria used in this analysis. All but three of these neighborhoods have populations that are greater than 50% people of color, and half of these neighborhoods have populations that are greater than 75% people of color. This shows that, in the TCMA, communities of color are most vulnerable to the UHI, and mitigating high urban temperatures is important for promoting environmental justice.

Table 2.6 Summary of TCMA census tracts that experience the UHI effect, have >50% impervious surface coverage, are ACPs, and have high proportions of high-risk age groups

Census Tract ID	City/Neighborhood	Population	% of TCMA population	% of population that is BIPOC	Total surface area ($miles^2$)	% of TCMA surface area
27053026819	Brooklyn Park	4698	0.15%	81.0%	0.45	<0.1%
27003051501	Columbia Heights	3159	0.10%	39.0%	0.58	<0.1%
27053021502	New Hope	4183	0.13%	54.2%	0.20	<0.1%
27053024802	Richfield	3198	0.10%	61.7%	0.18	<0.1%
Census tracts in Minneapolis						
27053102300	Hawthorne and Near-North	1,411	0.04%	82.4%	0.37	<0.1%
27053103400	Sumner-Glenwood and Near-North	2,915	0.09%	89.7%	0.74	<0.1%
27053100900	McKinley and Folwell	5,085	0.16%	75.1%	0.17	<0.1%
27053005901	Elliot Park	3,302	0.10%	48.1%	0.18	<0.1%
27053002200	Hawthorne	1,519	0.05%	85.9%	0.38	<0.1%
27053126000	Phillips West	5,066	0.16%	78.8%	0.58	<0.1%
27053104800	Cedar Riverside,	9,106	0.29%	69.7%	0.38	<0.1%
27053008500	Powderhorn Park	4,593	0.15%	60.9%	0.24	<0.1%
27053008200	Lyndale	4,681	0.15%	61.5%	0.78	<0.1%
27053106000	Ventura Village	3,517	0.11%	83.6%	0.45	<0.1%
27053103100	St. Anthony East	2,213	0.07%	29.3%	0.40	<0.1%
27053005902	Ventura Village	3,436	0.11%	76.6%	0.27	<0.1%
Total	-	*62,082*	*1.97%*	*100.0%*	*6.35*	*0.2%*

Additionally, we find that ACPs bear a disproportionate risk of facing the public health and economic challenges posed by the UHI. Although ACPs represent only 14% of all census tracts within the Twin Cities Metro Area, they represent 31% of the census tracts that experience average temperatures of above 95°F on a hot summer day. In terms of population, residents of ACPs make up 9.9% of the total population of the TCMA, but 29% of the population that lives in census tracts impacted by UHIs. These findings underscore the importance of installing BioSolar systems as a UHI mitigation strategy in ACPs that are impacted by high temperatures.

We discuss the importance of installing BioSolar systems for the sake of improving livelihoods within census tracts that are ACPs and predominantly inhabited by communities of color. It is important to consider the potential unintended harm of introducing new, potentially desirable green developments to low-income communities. In the following sections, we will discuss equity and gentrification, and how BioSolar systems may have negative social impacts when installed where most needed.

Chapter Three: Equity and Gentrification in Context with BioSolar System Policies

3.1 Introduction

Areas of concentrated poverty (ACPs) have not been consistently measured or classified, but are acknowledged as a historical and current problem in the United States that needs to be addressed through more inclusive and equitable planning practices. After "white suburbanization in the 1950's", wealthy populations of urban areas were able to build suburban areas that were spacious and far away from the perceived unsafe environments in downtowns across the nation (Frey, 1979). In the TCMA, we see within urban census-tracts in and near Minneapolis and St. Paul that there are significant areas of concentrated poverty. As seen in figure 3.1, some of these tracts are beginning to gentrify as a result of development creeping inwards from the outskirts of these urban cores.

We explore an economic pathway of gentrification, developed in *section 3.2*. This pathway illustrates how as new developments are installed, property values can rise, leading to increases in property taxes and yearly rents. The outcome of these higher costs could be displacement. This one pathway is not comprehensive of the forces at hand, but gets to the heart of economic realities behind displacement. Regardless of intent, the market empowers wealthy residents and simultaneously disempowers low-income residents.

Figure 3.1 compares areas of concentrated poverty to gentrified areas in the Twin Cities. Despite few census tracts transcending the boundaries of ACP into gentrified areas, many of these tracts are neighboring each other and show that in the future the overlap may be extreme for deeply impoverished areas.

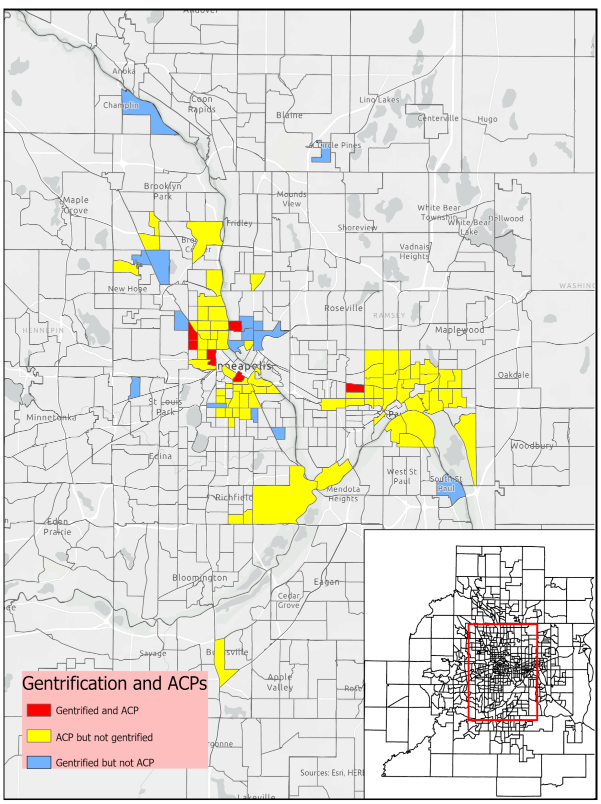


Figure 3.1. Census tracts that are ACP's, have gentrified, or both

Thus, we can thread a relationship between increased effects of UHI to areas of concentrated poverty, which are already susceptible to inequitable development practices (as discussed in Chapter 2). Then, we can connect ACPs to gentrifying areas, suggesting that gentrifying areas are also at risk of increased UHI impacts. This theory leads us to investigate the impacts of

BioSolar systems on gentrification and how socioeconomic factors, such as ACP's, contribute to the market forces behind displacement.

3.2 Conceptual Framework for Equity and Gentrification

Planning for equity commonly refers to using resources to bring different populations to the same "starting point", rather than assuming all populations are at the same "starting point" and allocating resources equally (as is the case in equality). Our operational definition of equity was derived from major themes from key informant interviews. The themes include wealth (on the community level), job opportunities and training, and education. BioSolar installations have the potential to produce commodities such as solar energy, food items, or cut flowers. These commodities can potentially generate income or be consumed directly by tenants, so equity also encompasses keeping the benefits from these commodities within the local community.

Gentrification is a large and complex issue, and requires a longer definition. We have developed a logic model that displays pathways through gentrification which we believe are relevant to BioSolar installations. Gentrification typically is discussed around wealthier, more affluent demographics moving into "undesirable" neighborhoods or otherwise displacing historical residents (Kirkland, 2008), however we recognize that this conceptualization diminishes the agency of people who are experiencing displacement. This is especially troubling since displaced populations are often communities of color, low-income communities, or other marginalized populations. Our logic model therefore focuses on the agency of a community undergoing displacement and highlights reasons why a given person would choose to leave their neighborhood. It is important to clarify that 'active choice' does not negate the experience of displacement. A person may choose to leave precisely because they feel "forced out" of their neighborhood, demonstrating that choice and displacement are not mutually exclusive.

It should be emphasized that this logic model is simplified. Our model focuses in particular on the processes leading to a current resident of a neighborhood undergoing gentrification deciding to leave their neighborhood and does not encompass all processes that make up gentrification. Certain intermediate steps have been omitted because they are dependent on the circumstances of any given neighborhood.

The purpose of this logic model is to provide a starting point for policymakers to engage with gentrification processes. The steps outlined act as prompts for policymakers to construct their analysis of a gentrifying neighborhood and see where they may be able to divert the process.

3.2.1 Amenity v Infrastructure

Installation of BioSolar systems in a neighborhood can affect residents in many different ways, we summarize major categories of effects in Figure 1 below. There is some debate if BioSolar systems should be conceptualized as infrastructure or as amenities; because of the variety of ways BioSolar systems can be utilized we are entering the debate with a "Yes, and" answer. BioSolar systems integrate solar panels (infrastructure) and greenery (amenity). Because of this, the connection between BioSolar systems on public and commercial buildings and residential effects like raising property taxes or rents is complex.

Existence value - value generated merely because something exists - plays an important role in a person's willingness to pay. Katz and Glassbrook (2018) support this logic; while their report on urban resilience does not monetize the aesthetic benefits of green roofs, they acknowledge there is an inherent aesthetic benefit to individuals in surrounding buildings with a view of the green roof, even if they cannot access it. If a person considered BioSolar systems to be more on the infrastructure side, proximity to an installation may not factor into their willingness to pay for living space. But if a person considers BioSolar systems to be an amenity, the installation may very well factor into their decisions.

This is further complicated by the variety of designs BioSolar systems can have. A BioSolar system may be designed completely as infrastructure in order to capitalize on solar energy and the environmental benefits of green roofs (and even here, environmentalists and like-minded people would consider this an amenity). Or BioSolar systems can be designed as social spaces that are meant to be accessed and used by people as an amenity; these designs would still be capable of being productive as infrastructure. Given this complexity, we are unable to conclude that BioSolar systems *do not* have an effect on resident willingness to pay decisions and we are unable to conclude that they *do* have an effect since both outcomes are possible.

A caveat to this discussion is that key informants from Minnesota and Canada (cold climates) did not tend to think of green roofs as socially usable spaces. Green roofs tended to be characterized as roofs that had plants on them and not much beyond that. Key informants from Colorado (a warmer climate for many months of the year) tended to think about and discuss green roofs as potentially socially usable space. Mordecai Children's Garden was used as an example when discussing how access to a green roof can affect a community (Green Roofs of Colorado, 2021). This is not to say that green roofs, and by extension BioSolar systems, would never be socially usable spaces, just that use and accessibility must take the winter climate into account.

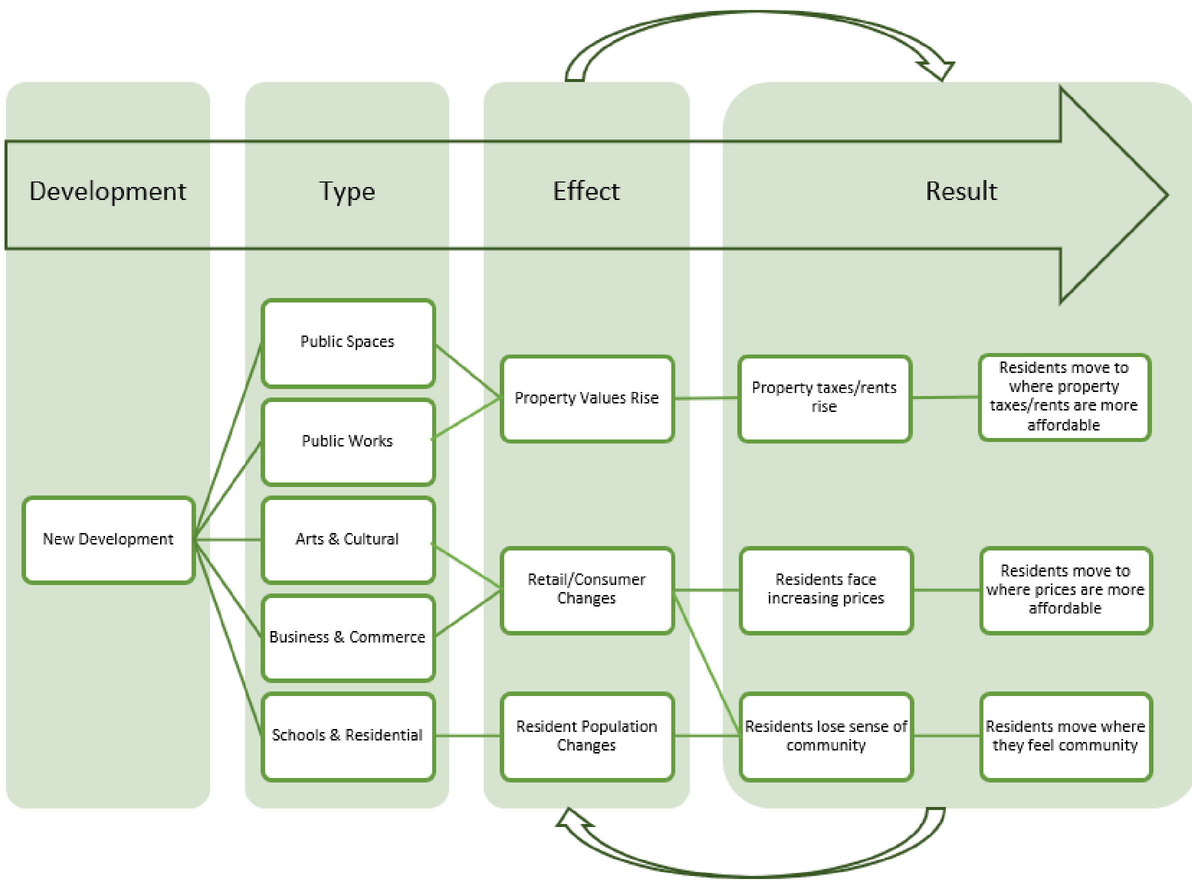
3.2.2 Logic Model

We conceptualized three pathways for gentrification to occur depending on the land use of the host building:

1. Property Values Rise
2. Retail/Consumer Changes
3. Loss of Sense of Community

Installation of BioSolar systems could affect a neighborhood's vulnerability to all three pathways. Following this model, as BioSolar systems are installed on both public and commercial buildings, property values would be affected and the retail landscape may change. If a BioSolar system is installed on a commercial building either commercial rent could increase due to the desirability of hosting your business in a "green" building[2], and force out small businesses, or larger chain stores may be attracted to the area. If the retail landscape changes, it could lead to residents facing increasing prices for amenities accessible to their location or the loss of familiar business may lead to residents losing their sense of community with their neighborhood. As a result, historical residents may choose to move to neighborhoods they find more desirable. This is a generalized high-level description of the process; section 3.4.2 below provides examples with more detail.

Figure 3.2. Gentrification Pathways Logic Model



"Resident" refers to the historical resident of a neighborhood, except in the bubble "Resident Population Changes".

[2] One key informant, a practitioner, stated that usually the retail businesses would change in a neighborhood with a new green roof installed on a commercial building. This change would be followed by changes in neighborhood residents.

Sense of Community.

While interventions may be developed to address any of the effects or results specified in the model, Loss of Sense of Community has been identified as a key step to address. Loss of Sense of Community contributes directly to two of the three pathways and peripherally to the third (as your friends and neighbors move away to more affordable neighbors, you are more likely to do so as well). Especially during the Covid-19 pandemic, the role of community connectedness has been highlighted for its role in mental health of individuals and communities. Many key informants talked about community in various ways (fostering community, building community wealth, serving local communities, engaging communities, as some examples), implying that "community" was the unit of interest, not "population" or "individual." Especially from the activist/advocate side of the conversation, there was importance associated with respecting a community as a community to acknowledge that people were connected and not simply living near each other without knowing each other. When connections within a community are cut or worn away, people feel less inclined to stay and this creates room for gentrifiers to move in. Given the large role loss of community plays in gentrification, keeping a neighborhood's sense of community intact will be key to preventing or mitigating displacement of residents.

Gentrification and Cultural Displacement.

Richardson, Mitchell, and Franco (2019) compiled a report for the National Community Reinvestment Coalition which focused, in part, on the question of if gentrification necessarily led to racial displacement.

"Neighborhoods experience gentrification when an influx of investment and changes to the built environment leads to rising home values, family incomes and educational levels of residents. Cultural displacement occurs when minority areas see a rapid decline in their numbers as affluent, white gentrifiers replace the incumbent residents."

They found that racial displacement often accompanied gentrification, but could not conclude that this is always the case. While our logic model does not distinguish between gentrification and cultural displacement and instead shows a potentially smooth transition from one process to the next, we wanted to highlight that the processes are not one and the same. As more is understood about this relationship the above logic model can be refined to better reflect the links between gentrification and eventual displacement of residents.

3.3 BioSolar, Low-Carbon Gentrification & Displacement

In the following section we outline how displacement could occur following the installation of green infrastructure (GI). This expands upon the logic model, which suggests new development has misaligned economic impacts on neighborhoods, so that as the property values rise displacement occurs and poor neighborhoods are no longer compositionally the same. This process is paralleled by environmental impacts on neighborhoods vulnerable to environmental harm, which experience less benefits from GI and transposed risk from proximate neighborhoods. Together, these forces contribute to the experiences of low-carbon gentrification that we theorize Biosolar systems may cause.

Over time, inequitable investment can lead to an association of GI being a luxury accommodation and in turn can lead to displacement. As Shokry, et al. (2018) define it,

"Sites of Omission (SO) as areas with higher social and ecological vulnerability that have been left out while economically valuable areas have been protected and prioritized; while Sites of Commission (SC) are those that receive protection, but gentrify over time or lead to the displacement of low-income and minority groups."

Sites of Commission are those that are most likely to be met with pushback from the community. Pushback stems from a fear of increasing property values associated with GI installation. This fear is a precursor to anticipated gentrification permeating vulnerable neighborhoods and dislocating communities to locations with extraneous risks (Shokry, et. al, 2018). Not only is this fear of GI installation intended to be preventative of displacement, but it is an expression of distrust in the power dynamics at hand in response to recent and growing awareness of climate change's severity.

Similarly, researchers Bouzarovski, et al. (2018) argue for a need for discourses of green gentrification experiences beyond what has been treated as displacement traditionally, and define low-carbon gentrification as the "process of changing the social and spatial composition of urban quarters under the pretext of climate change and energy efficiency imperatives," which is supported by evidence across Europe and throughout major urban hubs in the United States (Bouzarovski et al., 2018). Additionally, as green development is introduced, it increases property value through proximity to improved aesthetics, less air pollution, and the like. This in turn causes a 'green rent gap' to divide the original community into those who can afford the socio-ecological benefits and those who cannot (Blok, 2020).

Similar to the experiences of vulnerability to extreme heat conditions from section *2.6* , this displacement aggregates benefits of GI to the wealthy and transposes additional risks to other neighborhoods, in which a 'risk underclass' has been enforced a responsibility for consumption they have had little or no access to (Blok, 2020). Not all GI is at such a large-scale however, as the housing sector is also identified for increasing displacement of low-income residents. For example, the term 'renoviction' has been used to describe "efforts to remove individuals or groups of tenants after landlord-led refurbishments of buildings *(Ärlemalm, 2014; Hodkinson and Essen, 2015)*," with housewares such as reduced-flow water faucets and energy-efficient appliances (Bouzarovski, et al., 2018). It is noted that these are extreme cases of displacement, due to gentrification being well-established.

3.4 An Exploratory Econometric Analysis of BioSolar-Related Gentrification

While much of our research focused on theories of gentrification and neighborhood change as they relate to green developments, we sought empirical evidence of BioSolar-related gentrification within the TCMA. To do this, we operationalized the first path of the logic model (Figure 3.2) to see if new green developments in public spaces were associated with gentrification through the causal mechanisms described in the previous sections. We conceptualized green roofs, solar PVs and BioSolar systems on commercial and public properties as new developments that could increase property values in adjacent areas and potentially displace current economically disadvantaged residents (Bouzarovski et al., 2018). To perform this analysis, we adapted the research design and methodologies used in Rigolon and Németh's article *Toward a Socioecological Model of Gentrification: How People, Place, and Policy Shape Neighborhood Change* (2019), after cross-referencing their theoretical construct with a systematic review of gentrification literature by Padeiro et al. (2019).

This section details our process of adapting their research design, our statistical analysis within the TCMA, our preliminary findings, the limitations of our analysis and our proposed solutions to those limitations. *Section 3.4.4* discusses our preliminary findings on page 29.

3.4.1 Adapting Toward a Socioecological Model of Gentrification

Rigolon and Németh's article detailed three layers of characteristics that influence gentrification: people, place, and policy. Within the people layer are factors such as race and socio-economic status. In the place layer are factors such as access to transit and distance from downtown. Within the policy layer are factors such as the presence of subsidized housing. Rigolon and Németh argue that the combination of these three layers better explain the factors that contribute to, or prevent, gentrification better than any one layer in isolation.

Their research uses census tracts from the 2000 Census as its unit of analysis. Their study then regresses gentrification-susceptible census tracts on variables within the three layers during the 2000-2015 time period to see if those tracts *actually* gentrified over time. To perform their analysis, Rigolon and Németh constructed the following regression model to predict whether these susceptible tracts would gentrify:[3]

$$\mathbf{Y = \alpha + \beta_1 PEOPLE + \beta_2 PLACE + \beta_3 POLICY + \varepsilon} \qquad \text{where,}$$

Y = a term to indicate whether a gentrification-susceptible census tract gentrified by 2015
α = Constant term
PEOPLE = a vector of characteristics pertaining to the population of a given census tract

[3] β represents a coefficient that gives the impact a predictor variable (e.g. a People variable) has on an outcome variable (e.g. Gentrification). In this model, each variable within a given vector would have its own coefficient. For simplicity, these variables have been omitted in this depiction of the model in favor of the broader categories of gentrification determinants.

PLACE = a vector of characteristics pertaining to a given census tract itself
POLICY = a vector of characteristics pertaining to housing policy within a given census tract
Ɛ = an error term

Table 3.1 summarizes the model's predictor variables and basic hypotheses about how they might affect the likelihood of a tract to gentrify. Table 3.1 also identifies changes we made to Rigolon and Németh's original model. Our adaptations occur within the Place layer and the Policy layer. In the Place layer, Rigolon and Németh originally included a variable to account for the presence of a rail station nearby or in a tract. We excluded this variable because the Blue Line of the Light Rail, which operates in the Twin Cities, was still under construction midway through the timeframe of our analysis.

Table 3.1 Predictive Model Variable Descriptions

Name	Measurement	Hypothesized Effects	Effect
People Variables			
% Black	% of tract population	Higher percentage of Black residents → more susceptible to gentrification	+
% Latino	% of tract population	Higher percentage of Latino residents → less susceptible to gentrification	-
Income (2000)	2000 income adjusted to 2015 U.S. dollars	Higher 2000 income → less susceptible to gentrification	-
Place Variables			
Downtown distance	Miles from largest CSA downtown area	Farther from downtown → less susceptible to gentrification	-
Green Roofs*	Whether tracts have a green roof within ¼ mile, installed between 2000 and 2010	Presence of green roof → more susceptible to gentrification	+
Solar Panels*	Whether tracts have a solar panel within ¼ mile, installed between 2000 and 2010	Presence of solar panels → more susceptible to gentrification	+
Either GR or SP*	Whether tracts have a green roof OR solar panel within ¼ mile, installed between 2000 and 2010	Presence of either → more susceptible to gentrification	+
% Multifamily Housing	% of total housing buildings that are multifamily housing buildings (e.g. apartment buildings)	Higher percentage of multifamily buildings → more susceptible to gentrification	+
% Units 30 years or older	% of total housing buildings that are 30+ years old	Higher percentage of old buildings → more susceptible to gentrification	+
Population Density	Population per square mile	Higher population density → more susceptible to gentrification	+
Policy Variables			
Public Housing rate*	Number of subsidized housing units per 1000 residents	Higher public housing rate → less susceptible to gentrification	-

+ denotes a positive relationship - denotes a negative relationship o denotes unknown relationship
* denotes a change from Rigolon and Nemeth's original model

Instead, we included variables that account for the presence of green roofs and solar panels installed on existing properties between 2000 and 2010. We limit our data to installations on *existing properties* because we sought to capture the *marginal increase* in the likelihood of a tract to gentrify associated with solar panels or green roofs, not with new property developments.[4] We limited our data to installations built between 2000 and 2010, because we want to capture the marginal increase in the likelihood of a tract to gentrify associated with the introduction of *new* installations, not with those from before 2000. We excluded installations built after 2010 because we wanted to allow a five year period during which gentrification could occur, if it occured at all.

Our final change to the model was in the Policy layer. Originally, Rigolon and Németh used multiple subsidized housing variables to capture negative correlations between those programs and gentrification. Our model captures the same theoretical consideration, but operationalizes it with a Public Housing Rate variable. This change was due to limitations to the housing data available for the TCMA. Data sources for each variable can be found in Table A2(1).
After these changes, our model was the following:[5]

$$\mathbf{Y = \alpha + \beta_1 PEOPLE + \beta_2 PLACE + \beta_3 POLICY + \mathcal{E}} \qquad \text{where,}$$

Y = a term to indicate whether a gentrification-susceptible census tract gentrified by 2015
α = Constant term
PEOPLE = variables pertaining to those who lived in a given census tract, composed of
- % Black
- % Latino
- Median Household Income

PLACE[6] = variables pertaining to a given census tract itself, composed of
- Downtown Distance
- % Multifamily Units
- % Old Buildings
- Population Density
- Green Roofs OR Solar Panels OR Either

POLICY = subsidized housing rate in a census tract
Ɛ = an error term

With our model defined, we then had to identify gentrification-susceptible tracts and tracts that gentrified between 2000 and 2015.

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[4] Future studies should control for new property developments in a given area. Due to time and data limitations, our study was unable to do so. Controlling for new property developments would allow researchers to expand the number of solar panels and green roofs within their analysis, by including those that exist on new buildings. More importantly, controlling for new property developments would allow the model to account for a strong gentrifying force.
[5] Note that each variable within a given vector has its own coefficient. For simplicity, these variables have been omitted in this depiction of the model in favor of the broader categories of gentrification determinants.
[6] As noted before, we recommend future studies add a "New Property Developments" variable to the Place vector of characteristics.

3.4.2 Identification Methodology

To conduct this analysis, we had to distinguish gentrification-susceptible tracts from susceptible tracts. Next we had to determine whether a susceptible tract *actually* gentrified. Table 5.2 shows how we identify these tracts, following Rigolon and Németh's methodology.

Table 3.2 Operationalizing Tract Identification

Variable	Criterion
Tracts Susceptible to gentrification meet three of the four criteria	
Low household income	% households with income below 80% of census tract median > CSA median
% College	% residents with bachelor's degree < CSA median
% Renters	% renters > CSA median
% Persons of Color	% persons of color > CSA median
Gentrified tract meet the two criteria on income & college graduates, and at least one of the housing price criterion	
Low Household Income	Change in median household income > change in CSA median
% College	Change in % college educated > change in CSA percentage
AND	
Median gross rent	Change in median gross rent > change in CSA median
OR	
Median home value	% increase of home value > % increase in CSA median

**Table is adapted from Rigolon & Németh (2019)

Following these methods, we were able to identify gentrification-susceptible tracts and tracts that gentrified over time in the TCMA. Figure 3.3 shows the results of this process. Once we had identified these tracts within the TCMA, we were able to begin our statistical analysis.

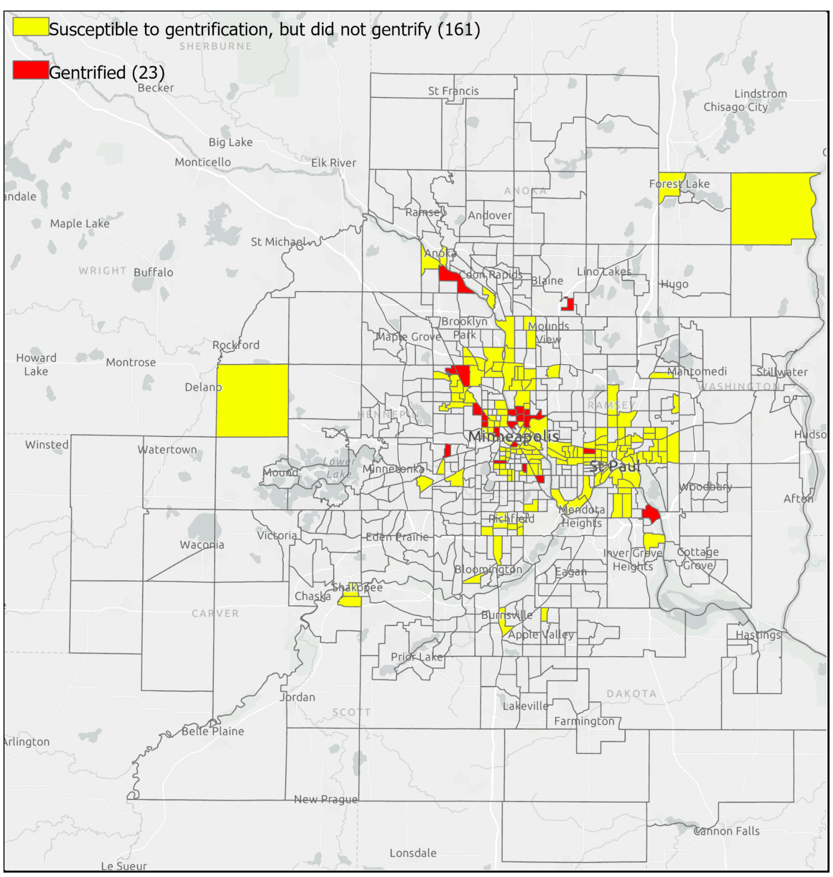

Figure 3.3 Twin Cities Gentrification- Susceptible Tracts and Tracts that Gentrified

3.4.3 Statistical Analysis

Our statistical analysis followed the process of Rigolon and Németh's original study. First, we conducted *t*-tests[7] to uncover differences in predictor variables between gentrification-susceptible tracts that gentrified and those that did not (Table 3.3). We also performed *t*-tests for tracts that were gentrification-susceptible and those that were *not.*

Table 3.3 Mean values of predictor variables across tract categories in the Twin Cities

	AMONG ALL TRACTS Gentrification Non-susceptible (GN) vs Susceptible (GS)		AMONG SUSCEPTIBLE TRACTS Susceptible but not Gentrified (GS-N vs Actually Gentrified (GS-G)	
	GN	GS	GS-N	GS-G
# of tracts	519	184	161	23
% Black (2000) ^	**4.4%*****	16.4%	15.2%	**24.7%*****
% Latino (2000) ^	**2.7%*****	7.1%	7.1%	6.8%
Median Household Income (2000)	**$86,979*****	$49,958	$50,123	$48,720
Downtown Distance (miles) (2000)	**11.2*****	4.6	4.6	4.1
% Multifamily Units (2000) ^	**21.4%*****	48.0%	48.3%	46.3%
% Old Buildings (2000) ^	**42.5%*****	72.5%	72.0%	76.4%
Population Density (2000) ^	**3,002.1*****	7,366.4	7,336.3	7,577.4
Public Housing Rate (2000) ^	**6.6*****	36.3	37.0	31.1
% of tracts that had a new green roof or solar panel built in or near them between 2000 and 2010				
Solar Panel	**9.6%****	14.1%	12.4%	**26.1%****
Green Roofs	**6.0%*****	23.4%	23.0%	26.1%
Either	**13.7%*****	32.6%	31.7%	39.1%

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$

^ denotes a weighted average used for percentage and rate variables.

Note: Because GN is compared to GS and GS-G is compared to GS-N, significant differences from GS and GS-G are notated in the columns of GN and GS-G.

Note: Monetary amounts are expressed in 2015 U.S. dollars.

We conducted multicollinearity tests across the predictor variables and found no confounding multicollinearity. Next, we conducted univariate *t*-tests on the benchmark variables that determined whether tracts gentrified over time (Table 3.4).

[7] *T*-tests are used to determine if there is a statistically significant difference between the means of a given characteristic across two different groups.

Table 3.4 Mean values of indicator variables across tract categories in the Twin Cities

	AMONG ALL TRACTS Gentrification Non-susceptible (GN) vs Susceptible (GS)		AMONG SUSCEPTIBLE TRACTS Susceptible but not Gentrified (GS-N vs Actually Gentrified (GS-G)	
	GN	GS	GS-N	GS-G
# of tracts	519	184	161	23
2000 values				
% Renters ^	**20.7%*****	49.1%	48.9%	**50.4%**
% POC ^	**11.8%*****	35.4%	34.2%	**44.0%****
% College ^	**37.6%*****	23.1%	23.7%	**18.5%****
Median Household Income	**$86,979*****	$49,958	$50,123	$48,720
Median Rent	**$974*****	$768	$771	$745
Median Home Value	**$230,644*****	$146,694	$149,118	**$129,731*****
2015 values				
% College ^	**28.8%*****	20.0%	19.6%	**23.2%****
Median Household Income	**$79,694*****	$44,711	$43,723	**$51,630****
Median Rent	**$1,132*****	$918	$912	$965
Median Home Value	**$244,020*****	$182,729	$182,614	$183,526

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$
^ denotes a weighted average for percent and rate variables.
Note: Because GN is compared to GS and GS-G is compared to GS-N, significant differences from GS and GS-G are notated in the columns of GN and GS-G.
Note: Monetary amounts are expressed in 2015 U.S. dollars. As such, the decline in Median Household Income in GN tracts reflects the failure of wages to keep pace with domestic inflation.

After limiting our sample to tracts that were gentrification-susceptible, we only had 184 observations (i.e. census tracts). We ran statistical power tests using a range of minimum detectable impacts and confirmed the sample size within the TCMA was too small. According to the results of our power tests in Table A2(6), the sample would need approximately ten times more observations to detect a 10% increase in the likelihood of a tract to gentrify over time.

3.4.4 Preliminary Findings

Despite the absence of regression results, there are noteworthy takeaways from this analysis.

Significant Differences in Benchmark Variables

The *t*-tests comparing the averages of each indicator variable in tracts that gentrified over time and those that did *not* revealed statistically significant differences between these tract categories

(Table 5.4). We found similar results when comparing the averages of indicator variables in gentrification-susceptible tracts and non-susceptible tracts (Table 5.5) These findings bolster the notion that Rigolon and Németh's identification methodologies work in the TCMA context.

Differing Significance in Predictor Variables

The *t*-tests also revealed several trends within the variables used to *predict* whether a susceptible tract would gentrify over time. The average of every predictor variable was statistically significantly different across gentrification-susceptible tracts and non-susceptible tracts (Table 5.3). For example, on average, gentrification-susceptible tracts had a much lower median household income than non-susceptible tracts in 2000. Susceptible tracts were also much closer to downtown city centers than non-susceptible tracts, on average.

Our variables of interest (green roofs, solar panels, or either) also showed statistically significant differences across susceptible tracts and non-susceptible tracts at the 0.05 level. In particular, 14.1% of susceptible tracts had a solar panel installed in or near them on a public or commercial property between 2000 and 2010; only 9.6% of non-susceptible tracts experienced the same. Similarly, 23.4% of susceptible tracts had a new green roof installed in or near them on a public or commercial property between 2000 and 2010, versus only 6% of non-susceptible tracts at the 0.01 level. These results suggest there is a statistically significant difference in the installation patterns of green developments between susceptible and non-susceptible tracts.

The *t*-tests comparing the averages of predictor variables across tracts that gentrified over time and those that did *not* tell a different story. In the TCMA, there were only two predictor variables that had statistically significantly different averages between these two categories. First, the percentage of the population that was Black in a gentrified tract was significantly higher than in tracts that did *not* gentrify at the 0.01 level. Second, the percentage of census tracts that gentrified had more solar panels installed in or near them on average than census tracts that did *not* gentrify at the 0.05 level.

3.4.5 Limitations and Potential Solutions

This section details the limitations of this econometric study of gentrification as well as potential solutions to these limitations should the Metropolitan Council decide to replicate it.

Insufficient Statistical Power

The insufficient statistical power, which prevented us from running a regression, is perhaps the largest limitation of this research. Fortunately, because the data represents the entirety of the TCMA, we were able to glean useful information from the *t*-tests performed in this analysis. If the Metropolitan Council seeks to identify with more certainty correlations between BioSolar elements and gentrification, they must expand the number of observations in this study. The following discusses two options for increasing the number of observations.

Option #1: Seek more granular data

By choosing a unit of analysis smaller than a census tract, researchers could obtain more observations in a given area and increase the statistical power of this study. This option would allow the Metropolitan Council to gain insight about the correlation between BioSolar elements and gentrification exclusive to the TCMA. However, collection of more granular data will likely be time consuming and potentially cost-prohibitive.

Option #2: Expand the areas of analysis

By expanding the area of analysis, researchers could obtain more observations and increase the statistical power of this study. While this option lessens the Metropolitan Council's ability to gain insight into trends exclusive to the TCMA, it is likely less expensive than the previous option. Most of the data used in this analysis is publicly available from the sources listed in Table A2(1). However, data about the location and installation dates of green roofs may have to be collected from local green roof-related organizations in the expanded areas of analysis.

Incomplete Information

Throughout our data collection efforts, we found that few organizations have readily available inventories of public and commercial green roof installations within their area. As such, we must acknowledge that we may have missed some green roofs on commercial and public properties. However, we are confident in the completeness of our data regarding solar panels, given the comprehensive data sources that we used and cross referenced. That being said, it *is* possible that we missed some solar panels installed on commercial or public properties between 2000 and 2010. **If the Metropolitan Council replicates this study, they should attempt to obtain a complete and up-to-date inventory of these green roofs, solar panels, and BioSolar systems**.

Omitted Variable Bias

Omitted variable bias *will* be a problem for future studies that perform a full regression analysis. Due to time and data limitations, we were unable to account for the presence of new property developments between 2000 and 2015 in census tracts. Theory suggests a strong association between gentrification and new property developments. If this analysis is replicated with a full regression analysis, the absence of a variable accounting for these developments will bias the results. **As such, a variable that accounts for new property developments in the studied timeframe should be added to the regression model.**

Questions of Causality

The causal direction of changes in gentrification due to green roofs and solar panels are not entirely clear. Tracts could have gentrified at any time between 2000 and 2015; because we do not collect data from each year in this time period, it is impossible for us to know precisely *when* a tract gentrified. This makes causal inference a challenge, because it is possible gentrification within a tract predates the installation of solar panels or green roofs on commercial and public properties. **Panel data that includes information from every year between 2000 and 2015 could solve this problem.** However, data would need to be collected from alternative sources, because the U.S. Census Bureau does not collect the relevant data every year.

Need for More Nuanced Analysis

The current analytical framework categorizes census tracts in four ways; gentrification susceptible tracts versus non-susceptible tracts, and susceptible tracts that gentrified over time versus tracts that did *not*. These classifications ignore the possibility of a susceptible tract that did *not* gentrify over time, but over time became less susceptible to gentrification. A fifth tract classification accounting for such developments could add nuance to this econometric analysis and could potentially provide insights about a population's ability to "thrive in place." **The Metropolitan Council could incorporate this additional classification by replicating the methodology to distinguish susceptible tracts from non-susceptible tracts (Table 3.2) using data from 2015 instead of data from 2000.**

Chapter Four: Surface with Purpose Recommendations and Collaboration Considerations

The purpose of this report was to uncover the impact of BioSolar systems on UHI and to reveal equity and gentrification considerations of implementing such systems. In Chapter 2, we found that green roofs could reduce reduce ambient air temperature in a city by as much as the average temperature of a city could be reduced by 0.5-5.8°F if total impervious surface coverage is reduced by 50%; however, integrating green roofs with solar panels may lessen their cooling capacity. We also found that economically disadvantaged groups and people ages 0-4 or 65+ are at the highest risk from UHI. In Chapter 3, we developed a conceptual framework that explored a potential pathway leading from the installation of green developments on public and commercial properties to gentrification of surrounding neighborhoods. We found empirical evidence within the TCMA to support the validity of this pathway.

Our econometric analysis revealed statistically significant differences in the installation trends of green roofs and solar panels between tracts that were susceptible to gentrification and those that were not. On average, tracts that were susceptible to gentrification had more solar panels and green roofs installed on public and commercial properties in or near them between 2000 and 2010 than non-susceptible tracts. While our analysis is exploratory in the TCMA and should be affirmed by other empirical studies, our findings support that policymakers should consider the association between gentrification and green developments as they promote relevant policies. At the same time, our UHI analysis suggests that the communities who are at risk of being displaced are also the communities who stand to benefit the most from BioSolar systems. Our recommendations for the Surface with Purpose tool as well as recommendations for BioSolar implementation attempt to walk this delicate balance.

4.1 Surface with Purpose Recommendations

More research is needed at a variety of scales and in differing regions to identify how common these impacts are, but in our study we have acknowledged that these are outcomes with a high possibility of recurring, due to inequitable planning processes. We offer the following suggestions for policymakers to consider and connect with the communities they serve.

1. Maintain an updated list of neighborhoods most at risk to public health and economic impacts from UHI, allowing policymakers to prioritize these areas.
2. Add an Equity tab to the Surface with Purpose webpage to help reduce assumptions in climate resiliency planning. This section could focus on existing areas of environmental harm, income disparities, and gentrification at the scale used by the Metropolitan Council.
3. Within this tab, include tips for fostering collaboration with local communities on environmental justice. Tips could include ways of sharing information with local

communities and ways to promote community education about BioSolar installation and maintenance.

4.1.1 Maintain Updated Priority List of Neighborhoods

When planning BioSolar implementation for heat mitigation across the TCMA, census tracts that are most at risk for the public health and economic benefits posed by the UHI should be prioritized. As discussed in chapter 2, these census tracts include those that are above 95°F on a hot summer day, have surface areas that are >50% impervious, have high proportions of age groups that are most vulnerable to heat, and are areas of concentrated poverty.

In the TCMA, the following neighborhoods met these criteria, and should therefore be prioritized for BioSolar implementation: Portions of Columbia Heights, New Hope, Brooklyn Center, and Richfield; as well as the following neighborhoods of Minneapolis: Powderhorn Park, Lyndale, Phillips West, Ventura Village, Elliot Park, Cedar Riverside, Sumner-Glenwood, Near-North, Hawthrone, McKinley, and Folwell.

Prioritizing these neighborhoods will maximize the net social benefit of BioSolar installation. However, when implementing BioSolar in these communities, planners should consider the potential for gentrification caused by installing new and potentially desirable infrastructure in low-income neighborhoods. The following recommendations discuss how that may be done.

4.1.2 Equity Tab: Resources to Augment Climate Resiliency Planning for Surface with Purpose

In many climate resilience plans, assumptions that distribution of equal benefits are baked into policies without consideration for heterogeneous effects of GI as well as potential negative externalities felt by at-risk groups. Using UHI as an example, the assumption of equal reductions in air temperature across the city ignores the possibility that some neighborhoods may be more (or, perhaps less) than others. Policy should address how to implement GI without increasing likelihood of displacement.

The Metropolitan Council has taken significant steps to identify neighborhoods with high concentrations of marginalized populations, specifically those that historically have been affected by systemic racism. As the Metropolitan Council re-envisions their concept of ACPs, they should consider including additional variables of interest when prioritizing installation of GI, as well as mitigating potential adverse effects such as gentrification. These variables could include high proportions of elderly and infants susceptible to extreme heat events and the indicators for potential gentrification discussed in section 3.4. The analyses presented in this report provide an example of how the Metropolitan Council can augment current practices to address historic inequities by incorporating additional variables into spatial analysis.

Additionally, we recommend continuing to take inventory of existing areas of environmental harm, income disparities, and gentrification at the scale used by the Metropolitan Council. This should precede any and all steps to install GI systems. Such an inventory could be an opportunity to integrate equity into the Surface with Purpose tool and provide policymakers with a source for future equity consideration. Explicit information about the breadth and severity of the aforementioned conditions allows for policymakers to make evidence-based decisions about the needs of their constituents and their available resources.

4.1.3 Equity Tab: Foster Collaboration & Environmental Justice through Community Engagement

Several key informants expressed deep skepticism about policy approaches that are implemented without consultation and involvement of the local community. This can lead to the neglect of questions such as: who will receive the benefits of BioSolar systems and who will control the distribution of such benefits? By not collaborating, the distribution of benefits will be controlled by one party, affecting the received benefits of the local community. The Metropolitan Council's historic work on ACPs and their current reenvisioning of the concept prove that it has equity and inclusion as one of its highest priorities. Policy-makers and planners should continue to analyze histories and circumstances of neighborhoods before moving forward with initiatives in order to maximize potential for collaboration.

Along these lines, we recommend that the Metropolitan Council continue their participatory justice practices by incorporating communities and collaborating with non-profit organizations as they implement GI projects. Specifically, we recommend the inclusion of community members in onsite processes such as the installation and maintenance of GI systems. This not only serves as an educational and trust-building opportunity, but builds the capacity for co-leadership in future environmental initiatives at the neighborhood scale. The following section provides additional strategies that could be included within the Surface with Purpose tool's resources.

4.2 Considerations for Collaboration with Community Members

Equity and gentrification are important to consider together. While each individual installation of a BioSolar (i.e. a brewpub considering a BioSolar patio roof) may not warrant a full study in gentrification potential, the accumulation of inequitable designed BioSolar system installations have a strong chance of leading to gentrification of the neighborhood. Inequity is not sufficient (or even sometimes necessary) to lead to gentrification but does play a role in how connected residents feel to a neighborhood/community. Addressing equity early, in the design stages of BioSolar system policies, may produce a ripple effect of mitigating or possibly even diverting gentrification in a community.

The following sections describe major areas of consideration we identified from our key informant interviews with community members, practitioners, and policymakers as important to creating equitable designs of BioSolar system installations. The following sections do not present solutions; the following sections highlight important topics of discussion for continued collaboration with community members.

1. Geographic Considerations
    a. Public Benefits
    b. Property Values
2. Functional Considerations
    a. Private Benefits
    b. Access
    c. Maintenance, Sustainability, and Longevity

These considerations may seem granular or out of place for an analysis of gentrification (a decidedly large-scale phenomenon). As stated above, accumulation of inequitable projects may lead into or exacerbate gentrification, so addressing equity early in the design process, at the granular level, may work to mitigate or delay gentrification. The following sections do not provide policy recommendations or a checklist to ensure that a BioSolar installation will be equitable. This list presents areas of opportunities for policymakers, practitioners, developers, and community members to engage with equity and find creative solutions to opposing concerns.

4.2.1 Geographic Considerations

Public benefits and property values are spatial considerations. Chapter 2 is an example of a public benefit and Section 3.4 deals specifically with property values. The location of the BioSolar system installation is tied to where these benefits are felt and the equity of their distribution. Additionally, we found anecdotal evidence of zoning codes potentially being an obstacle in the rollout of green infrastructure (Dig Studios, 2020). New codes and/or interpretations may be needed to better facilitate rollout.

<u>Public Benefits from BioSolar Systems</u>

BioSolar systems generate numerous public benefits, such as reductions in UHI, water retention, clearer air, etc. (Barron-Gafford et al., 2016; Minnesota Pollution Control Agency, 2013; Gaffin et al., 2009). Because these types of benefits cannot be packaged and allocated, it is important to consider the physical location of BioSolar systems to ensure public benefits are distributed equitably across the Metropolitan Council’s jurisdictions.

Several key informants suggested that equitable distribution of these benefits would seem financially unfeasible from a developer’s perspective. This perceived infeasibility presents a challenge for incentivizing retention of residents in a gentrification-susceptible area. According to our key informants, any policy solution to resolve this must address two issues:

1. Financial Feasibility
2. Displacement of Current Residents

Financial feasibility could be addressed through market incentives (such as tax credits for maintaining BioSolar systems) or through appeals to social investment. Developers will need to be provided with education on BioSolar systems and their benefits and trained on how to maintain them. One key informant described to us how the perception of financial feasibility dramatically improved in Portland, Oregon as the local green roof industry grew and developers and practitioners refined their best practices. He stated that developers were at first resistant to green roofs because they were regarded as difficult to maintain and costly. As practitioners refined their design knowledge and were able to reduce the costs of maintaining green roofs, developers began to view them favorably. In some cases, involving apartment buildings, developers were very favorable to green roofs as tenants were willing to pay higher rents to live in a "green"[8] building, especially if the green roof was accessible to tenants.

Addressing concerns of displacement for current residents will likely involve housing policy to incentivize retention of renters (as many neighborhoods vulnerable to gentrification exhibit high rentership). Economic theory would suggest that rent be raised to offset the costs of installing and maintaining the BioSolar system. This leads to obvious complications with housing affordability for low-income rents. Potential policy interventions would consider how to move these increased costs off of rent tenants, while still making the BioSolar system financially feasible.

Property Values

Similar to public benefits, property values are a consideration that factors into the physical location of BioSolar systems. Literature documents the effect that new green spaces in cities can have on adjacent property values (Richardson, Mitchell, & Franco, 2019), potentially leading to displacement of residents as their property tax climbs. One key informant highlights a nuance to this issue. In his opinion, green installations that are designed and billed as "showcase" are more likely to have effects on property values, while green installations that are relatively inconspicuous are less likely. This is based on his own observations and is a topic of potential future study in the literature.

BioSolar installations that are designed to be accessed and utilized as gathering spaces are most likely to experience this problem. Consideration of how costs will be offset and distributed will be important to maintain tenants' access and access to benefits while mitigating possible effects on property values.

[8] In this case, 'green' does not refer to being green certified. This denotes the perception of being environmentally friendly by the general public.

On the other hand, if BioSolar installations do have an appreciable effect on property values, they can be used to maintain a neighborhood's wealth if a neighborhood is experiencing rapid decline in property values. By bolstering property values, wealthier residents may be less inclined to leave a neighborhood.

4.2.2 Functional Considerations

Private benefits, access, and maintenance are considerations concerning the function of the BioSolar system installation. These considerations are opportunities for community wealth building, both economically and socially.

Private Benefits from BioSolar Systems

In addition to public benefits, BioSolar systems produce private benefits such as solar energy, collected rainwater, and – depending on the plants used – food products. Our definition of equity includes the condition that benefits, where possible, remain local. This means that private benefits from products generated from BioSolar systems should remain accessible to the tenants of the building hosting the system, whoever that may be. Tenants should be treated as co-owners of these products because, ultimately, tenants paid for the installation of the BioSolar system through either rent or taxes. Policies should acknowledge this by prioritizing tenant access to share in the benefits and/or profit generated by the BioSolar system.

Examples include:

- Reduced utility costs (included in rent) for apartment tenants in a building generating solar energy
- Access for clients to gather food items from green roofs (implemented on at least one green roof for a homeless shelter in Los Angeles)
- Dividends distributed to apartment tenants in buildings that sell BioSolar products to third parties

Access to BioSolar Systems

Access can affect the design of a BioSolar system (for example, an apartment building offering access to tenants will want a space set up for social gatherings) and can facilitate distribution of private benefits. For example, one key informant discussed a project she had worked on in Los Angeles for a homeless shelter that wanted a green roof that produced food items clients would be able to harvest themselves. The access granted (and the desired outcome of that access) guided decisions such as what plants to use and how to space them.

Access also has the potential to offer intangible benefits to communities. A 2013 systematic review (the most recent on the subject) found that access to nature (including both plants and animals) had beneficial effects on human physical health, emotional/mental wellbeing, spirituality[9], creativity, and connectedness to community (Russell et al., 2013). This study looked broadly at "nature" and excluded only "nonliving human-built environments", since a BioSolar system is a living environment the findings of this study are applicable.

Since Sense of Community was identified by the logic model as key to mitigating displacement of residents (and therefore mitigating gentrification) and since access to nature (which BioSolar systems can be classified as) can foster a sense of connectedness to community, it follows that providing access to neighborhood residents to BioSolar systems will help to mitigate gentrification. Simply put, the more BioSolar systems can be integrated into people's daily lives and activities (like a public park), rather than marketed as a desirable amenity, the better the BioSolar system's impact will be on the community.

Maintenance, Sustainability, and Longevity

A BioSolar system is meant to be a longstanding installation - studies in Europe have shown that green roofing system lifespans can be more than double the lifespan of conventional roofing systems (Carter & Keeler, 2008) - and so will require maintenance and design for sustainability. Since BioSolar systems are not yet established as common amenities in many areas, there are not clear practices for maintaining them. Several key informants highly encouraged either training existing facilities staff or hiring new staff locally to maintain the BioSolar system as a strategy to spread more benefits through the community. By utilizing these strategies, community members have opportunities in education and gain marketable skills. The wealth of the community grows as wages generated by maintenance labor remain within the local community and flow through the local economy.

4.3 Future Steps

4.3.1 BioSolar and Urban Heat Island

While there is ample research on green roofs' potential to mitigate the urban heat island effect, there is relatively little knowledge about how that potential changes with the addition of solar panels. Accordingly, future research should focus on determining the cooling potential of BioSolar systems in the Twin Cities. Additionally, research on BioSolar's ability to mitigate the urban heat island in tandem with other green infrastructure should be further explored.

4.3.2 BioSolar and Gentrification

Green energy systems and urban sustainability initiatives have variable beneficial outcomes but can have unintended consequences. The discourse on green gentrification is still in preliminary stages, evidenced by many researchers having to work from anecdotal evidence or examinations of pre-existing policy literature in order to reduce unintended harms. Research on equitable

[9] Defined as a sense of connection to "otherworldly forces that go beyond what is generally considered to be within physical and mental health"

transitions to green energy, as well as the inequities underpinning these transitions, can shed light on what policies are needed in the future.

The Metropolitan Council is a leader in providing open-source and transparent data. Increasing access to this data to community members can build trust with the communities receiving GI systems by giving them a point of reference to understand project motivations and benefits. Inventories of existing disparities, as well as records of community involvement, should be maintained and publicized to foster trust and common knowledge of existing BioSolar projects.

While housing policy was outside the scope of this study, we recommend considering housing protections for neighborhoods vulnerable to gentrification. Housing policy has obvious implications for gentrification and merits its own study for the Surface with Purpose tool. The Metropolitan Council oversees housing policy within the TCMA and should consider integration of GI policies and housing policies.

Appendices

A1. Key Concepts & Terminology

Albedo (Solar Reflectance)	Albedo describes the percentage of solar energy reflected off any given surface (NSIDC, 2020). Materials, such as asphalt or concrete, typically used in urban construction are often dark and/or do not reflect as much of the sun's energy as other light-colored materials do. These darker surfaces absorb the sun's energy as heat at higher rates, and tend to be concentrated in the urban core. Due to this, low albedo is a key contributor to urban heat islands.
BioSolar Systems	Describes integrated systems of solar photovoltaic panels and green roofs.
Environmental Justice	As defined by the U.S. Environmental Protection Agency, Environmental Justice is "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA,2021). In current practice, advocates have adopted an affirmative stance to involve members of historically marginalized communities in decision-making and implementation of environmental policies.
Evapotranspiration	The process where vegetation releases water into the atmosphere (humidity) and cools air temperature. (USGS, 2021) Less vegetation yields lower rates of evapotranspiration. Urban areas have lower evapotranspiration rates than most rural areas due to less vegetation. This contributes to UHI.
Green Gentrification / Environmental Gentrification	The process by which urban sustainability initiatives have the unintended consequence of displacing current residents (Greenberg and Smith, 2021) through a variety of causal mechanisms. As with other forms of gentrification, green gentrification disproportionately impacts members of the BIPOC community.
Green Infrastructure	Green Infrastructure is the installation of environmentally friendly infrastructure, such as plant systems and permeable surfaces that manage wet weather impacts (EPA, 2020), including green roofs and solar panels.
Heat Capacity & Thermal Emittance	Heat capacity is the ability to store energy as heat. Typically, urban materials have twice as much heat capacity as materials in rural areas.

Thermal emittance is the ability of a material to radiate its stored energy as heat. Most materials found in urban areas have high thermal emissivity (EPA, 2020). These elements also contribute to UHI.

Impervious Surfaces — Surfaces that water cannot penetrate, such as cement and pavement. Impervious surfaces in the built environment drive UHI; localized flooding; poor air, water, and soil quality; and negative public health and economic impacts disproportionately felt across race and class.

Photovoltaic Solar Panels — Solar PVs capture light from the sun and convert it to electricity that can be used on-site or distributed through a connected energy grid. This is in contrast to thermal solar panels, which heat water collected and used by domestic buildings in lieu of (or in addition to) traditional water heaters. Our research focuses on the effects of Solar PVs.

Surface and Atmospheric Urban Heat Island — Surface UHI refers to the solar energy stored and radiated as heat on and near urban surfaces, such as blacktop roofs and roads. Contributors such as high heat capacity and low albedo in these surfaces cause increased temperature rates at human scale. Atmospheric UHI refers to the air temperature in urban areas that is caused by the slow release of energy previously trapped in urban surfaces. This increased temperature is felt as radiation throughout the urban 'canopy' or at building scale, causing a compounded high temperature rate (EPA, 2020).

Urban Heat Island Effect (UHI) — The Urban Heat Island Effect is the phenomenon by which urban areas experience higher temperatures on average than outlying areas. The high concentration of buildings, roads, parking lots, and other impervious surfaces found within urban areas combined with a low level of vegetative coverage cause daytime temperatures in these areas to be about 1-7 degrees fahrenheit higher than the temperatures of the surrounding areas (EPA, 2020). This increase in average temperature can exacerbate extreme heat and have adverse public health and economic impacts.

A2. Gentrification Model Summary Tables

Table A2(1). Model Variables and data sources used

Name	Description	Year	Source
Susceptibility			
Income	Median household income	2000	LTDB (tracts); NHGIS (CSAs)
% College	Percentage of people aged 25 or older with at least a bachelor's degree	2000	LTDB (tracts); NHGIS (CSAs)
% Renters	Percentage of rented housing units	2000	LTDB (tracts); NHGIS (CSAs)
% People of Color	Percent of racial and ethnic minority people: all minus non-hispanic White people	2000	LTDB (tracts); NHGIS (CSAs)
Gentrification			
Income	Median household income	2015	ACS (tracts & CSAs)
% College	Percentage of people aged 25 or older with at least a bachelor's degree	2015	ACS (tracts & CSAs)
Median gross rent	Median gross rent	2015	ACS (tracts & CSAs)
Median home value	Median value of owner-occupied housing units	2015	ACS (tracts & CSAs)
Predicting Gentrification			
% Black	Percentage of non-Hispanic Black Residents	2000	LTDB
% Latino	Percentage of Hispanic or Latino residents	2000	LTDB
Income	Median household income	2000	LTDB
Downtown distance	Distance from largest downtown in CSA	2000	Varied by tract
Green Developments	Tracts within ¼ mile of a green roof, solar panel, or BioSolar system	2000	Various Sources
% Multifamily Housing	Percentage of multifamily housing units	2000	LTDB
% Units 30 years or older	Percentage of housing buildings 30 years or older	2000	LTDB
Population Density	Population density (people per acre)	2000	LTDB
Public Housing rate	Number of government subsidized units per 1000 residents	2000	HUD

**Table is adapted from Rigolon & Németh (2019).

Table A2(2). Twin Cities Combined Statistical Area Summary Statistics

	2000	2015	% Change
Total Population	2,968,806	3,797,915	+ 27.9%
% College Educated	33.3%	38.2%	+ 4.9%
% Persons of Color	13.9%	18.3%	+ 4.4%
Median Household Income*	$74,744	$67,427	-9.8%
Median Gross Rent**	$922	$913	-1.0%
Median Home Value**	$203,187	$209,100	+ 2.91%
Housing Units	1,169,775	1547,859	+ 32.3%

* Value is in 2015 dollars. Using the CPI for income, the 2000 income amounts were multiplied by 1.3764.
** Value is in 2015 dollars. Using the CPI for housing, the 2000 housing value and rent amounts were multiplied by 1.4390.

Table A2(3). Illustrative Indicators for Tracts Susceptible to Gentrification (2000)

Location	Median HH Income	% College Educated	% Renters	% Persons of Color
Hennepin Cty (Tract 1,048)	$19,749	28.3%	78.6%	38.9%
Ramsey Cty (Tract 337)	$19,852	5.5%	65.3%	24.0%
Hennepin Cty (Tract 1,034)*	$20,580	3.7%	57.5%	77.2%
Hennepin Cty (Tract 1,039)	$22,080	59.4%	54.1%	15%
Hennepin Cty (Tract 1,023)	$22,189	16.0%	60.0%	24.5%

* Denotes a census tract that gentrified by 2015.

Table A2(4). Illustrative Indicators for Tracts that Gentrified over Time (2000)

Location	Median HH Income	% College Educated	% Renters	% Persons of Color
Hennepin Cty (Tract 1,034)	$20,580	3.7%	57.5%	77.2%
Hennepin Cty (Tract 1,054)	$26,847	21.1%	77.1%	21.7%
Hennepin Cty (Tract 1,259)	$31,794	8.4%	68.6%	85.1%
Ramsey Cty (Tract 324)	$38,753	12.4%	40.5%	26.9%
Hennepin Cty (Tract 77)	$39,178	29.4%	48.4%	19.2%

Table A2(5). Full Summary Statistics for Illustrative Tracts that Gentrified Over Time

	Hennepin Cty (Tract 1,034)	Hennepin Cty (Tract 1,054)	Hennepin Cty (Tract 1,259)	Ramsey Cty (Tract 324)	Hennepin Cty (Tract 77)
Median HH Income (2000)	$20,580	$26,847	$31,794	$38,753	$39,178
Median HH Income (2015)	$18,854	$44,659	$35,224	$47,768	$46,719
% College Educated (2000)	3.7%	21.1%	8.4%	12.4%	29.4%
% College Educated (2015)	9.3%	33.6%	15.4%	17.1%	35.2%
% Renters (2000)	57.5%	77.1%	68.6%	40.5%	48.4%
% Persons of Color (2000)	77.2%	21.7%	85.1%	26.9%	19.2%
Median Rent (2000)	$381	$590	$683	$676	$776
Median Rent (2015)	N/A	$663	$780	$781	$1,141
Median Home Value (2000)	$17,988	$127,064	$92,545	$110,371	$116,127
Median Home Value (2015)	$233,300	$271,400	$136,600	$168,500	$248,800
% Black (2000)	53.0%	10.3%	26.4%	12.2%	8.5%
% Latino (2000)	3.2%	5.2%	27.0%	4.9%	6.4%
Downtown Distance (miles)	1.3	0.5	N/A	2.3	2.1
% Multifamily Units	89.3%	96.9%	57.3%	39.3%	88.1%
% Old Buildings	42.5%	83.7%	70.9%	78.2%	63.0%
Population Density (miles^2)	3,889	9,844	N/A	7,145	13,612
Subsidized Units per 1,000 residents)	263	25	0	49	8
Green Infrastructure?	Yes	Yes	No	No	Yes

Table A2(6). Power Test Results

Alpha	Power	Non-Gentrified	Gentrified	Total Observations	Additional Observations Needed	Minimum Detectable Impact	Inter-Category Correlation
0.05	0.8	161	23	184	x 3	**0.15**	0.09711
0.05	0.8	161	23	184	x 10	**0.10**	0.09711
0.05	0.8	161	23	184	--*	**0.05**	0.09711
0.05	0.8	161	23	184	--	**0**	0.09711
0.05	0.8	161	23	184	--	**-0.05**	0.09711
0.05	0.8	161	23	184	x 4	**-0.010**	0.09711

* Dashes indicate prohibitive observations needed to detect that level of minimum impact.

Table A2(7). Gentrification Regressed On Varying Models

Predictor Variables	M1	M2	M3	M4	M5	M6	M7
% Black	-	-	-	-	-	-	-
% Latino	-	-	-	-	-	-	-
Median Household Income	+	+	+	+	+	+	+
Downtown Distance (miles)		-	-	-	-	-	-
Solar Panel		+	+				
Green Roofs				+	+		
Either						+	+
% Multifamily Units		+	+	+	+	+	+
% Old Buildings		+	+	+	+	+	+
Population Density		+	+	+	+	+	+
Public Housing Rate			-		-		-

+ denotes a predicted positive relationship between variable and likelihood to gentrify
- denotes a predicted negative relationship between variable and likelihood to gentrify
o denotes a predicted indeterminate relationship between variable and likelihood to gentrify

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Key Informants

Role	**Organization**	**Topics Discussed**
Researcher, Professor	University of Toronto	Green Roofs, Solar PV, UHI, Gentrification
Researcher, Policy Advocate	University of Colorado	Green Roofs, Gentrification, UHI
Contractor, Policy Advocate	Green Roofs of Colorado	Green Roofs, Gentrification, UHI
Contractor, Developer	AD Green Roofs	Green Roofs, Gentrification
Soil Expert, Environmental Activist	Community Environmental Boards	Green Roofs, Solar PV, Gentrification
Policy Advocate, Stakeholder Convener	Kandiyo Consulting and Green Infrastructure Foundation	Green Roofs, Solar PV, UHI, Gentrification
Entrepreneur, Policy Advocate	Renewable Energy Partners	Green Roofs, Solar PV, Gentrification
Policy Practitioner, Installation Specialist	Denver City Government	Green Roofs, Solar PV, UHI, Gentrification